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Rear Admiral, NONA
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SECTION 1

GENERAL

SUB-SECTION 1/1 - GENERAL

1. GENERAL

1.1 The purpose of AECP-1 is to present sources, characteristics and data samples for mechanical environments, particularly vibration and shock, that influence the design of defence materiel. This document does not address environments arising from accident or hostile conditions, or nuclear effects.

1.2 The information contained in this document is augmented in STANAG 4370 AECTP 200 Mechanical Conditions by the inclusion of data sheets summarising key references on major environments and also by guidance on the selection of suitable test methods.

2. APPLICATION

2.1 The characteristics and data contained in this AECP are intended for use in the following applications:

a. To permit customers, or potential customers to ask intelligent questions to confirm that key environmental characteristics and issues have been, or will be, addressed by suppliers, or potential suppliers.

b. To assist project engineers to compile Environmental Requirement (or Life Cycle Environmental Profile) specifications, through the identification of all major environments, and through the illustration and quantification of the key environmental characteristics and the parameters that influence their magnitude.

c. To assist project engineers in the preparation of Environmental Design Specifications, through the inclusion of improved environmental characteristics data, which is intended to provide the means for much improved initial design values.

3. POTENTIAL DAMAGING EFFECTS

3.1 The mechanical environments arising during the service use of materiel may induce a number of mechanisms of potential materiel failure. The most significant of these mechanisms are related to either displacements induced in the materiel or as a result of acceleration loadings. Induced displacements within the materiel may produce relative motions which in turn may result in collisions between equipments, tension failures and connectors becoming loosened. Acceleration related failures may arise through the action of inertia loadings. These may be applied once, to produce a threshold exceedance failure, or repeated to produce a fatigue induced failure. Failures induced as a result of an applied velocity are fairly unusual. However, the application of velocity loadings on some electrical equipment and certain types of sensors may induce spurious voltages. These in turn may give rise to functional failures.

3.2 The potential damaging effects associated with a specific major environmental condition are discussed, where relevant, under the environmental condition heading within the appropriate sub-section.

SECTION 2

TRANSPORTATION

SUB-SECTION 2/1 - ROAD TRANSPORTATION UP TO FORWARD BASE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during road transportation between manufacturing sites and forward storage bases. It specifically includes vibration and shock transients associated with road transportation, bounce imparted by dynamic interactions of the cargo platform and jostling due to collisions with other cargo. The sources and characteristics of the mechanical environments are presented and discussed. Advice is also given on potential damaging effects. Additional guidance is contained in Annex A on important parameters influencing the mechanical environments when materiel is carried as restrained cargo.

1.2 For the purpose of this sub-section, materiel exposed to the road transportation environment may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to vehicle axes, with the positive longitudinal axis of the right handed axes set coinciding with the direction of normal motion (ie: forward).

1.3 Transportation beyond the forward base, when environments associated with off road and combat conditions may be experienced, is the subject of Sub-section 2/5.

1.4 Handling conditions relevant to the loading and unloading of road vehicles, ie: hoisting, the use of forklifts, etc, are discussed in Sub-section 3/1.

2. MATERIEL CARRIED AS RESTRAINED CARGO

2.1 All the various road related sources of excitation produce at the payload a composite of continuous (vibration) and transient (shock) motions. For testing purposes, the resultant payload dynamic motions are usually considered as vibration responses and shock responses. For convenience these groupings are also used to discuss the characteristics of the environment. However, in reality the separation of vibration and shock can be difficult. Figures 1, 2, 3 and 6 contain typical descriptions of the road transport dynamic environment. The figures show for a 4 x 4 truck rms g vibration levels, acceleration power spectral density and peak hold spectra, amplitude probability density and distributions and a typical transient for the three principal axes. The figures show the same vehicle travelling over a range of road types (motorways, major roads and minor roads) at a range of speeds. The effects of road speed on rms g and peak g vibration levels are shown in Figures 4 and 5. The vehicle was loaded to approximately 50% capacity (by mass) and the payload was firmly attached such that no significant bouncing was permitted.

2.2 The predominant characteristics of the vibration components of the payload dynamic motions are essentially random and cover a relatively broad frequency bandwidth. Acceleration amplitudes tend to be higher at the lower frequencies and particularly at the vehicle suspension modes. As the vehicle suspension modes occur at relatively low frequencies, typically 4-10Hz, significant payload displacements can be induced. The most severe vibrations tend to occur in the vertical vehicle axis with lower levels occurring in the lateral and longitudinal axes. The angular motions cannot always be ignored particularly the pitching and to a lesser extent the rolling motions. The amplitude of the vibrations will be vehicle type dependent, but will also depend significantly on vehicle velocity. To a lesser extent, road surface can also be an influence. Some periodic motions may be superimposed on the payload responses originating from the engine and transmission system. Although the frequency of these motions will vary with engine speed they are usually of minor importance.

2.3 For many payloads the vibration environment arising from road transportation may be the most severe that it is likely to experience. However, as materiel is usually packaged during transportation, a reasonable degree of protection will probably exist. This protection is often designed to protect the materiel from shocks rather than vibration. As a result, in some packaging designs, significant amplification of the excitations can occur at certain modes of vibration. As these modes are usually of relatively low frequency (10-50 Hz), significant amplitudes can arise (with the possibility of secondary impacts of the materiel with the inside of its package). Such motions can be amplified by coupling of the vehicle suspension modes.

2.4 The transients (or shocks) will originate from the vehicle traversing pot-holes, kerbs and general discontinuities in the road surface. Hence the amplitude and profile will be dependent upon the 'shape' of the discontinuity. Due to the influence of the vehicle and its suspension system, the initial shock pulse will be followed by a rapid exponential decay. Even for the most severe shocks the amplitude of the responses decay to insignificance within 2 or 3 cycles. In most cases the dominant frequency component of the transient is that of the vertical vehicle suspension mode. The peak amplitudes of the transients appear to follow an approximately gaussian distribution. Although the rate of occurrence, and standard deviation will be influenced for a particular vehicle, by velocity and road surface condition. Typical road surface induced transients are shown in Figure 7 and their associated shock response spectra in Figure 8.

2.5 Although the amplitude of these shocks arising from poor road surfaces may not be particularly significant, the majority of the energy could well be below the frequency range where the anti-shock mounts of the payload are effective. Consequently the materiel may experience the transients without any effective protection.

3. MATERIEL CARRIED AS LOOSE CARGO

3.1 The motions originating from the payload bouncing on the cargo deck and jostling with its neighbours are usually, for test purposes, considered separately from the shocks or transients originating from the road surface. The reason for this separation is that the severity and characteristics of these shocks, as experienced by the payload, will be significantly different to the transients originating from the road surface.

3.2 The transformation of the available kinetic energy into a shock pulse will depend upon the structural stiffness of the two impacting faces (the load platform and the package). The stiffer the two impacting faces, the shorter duration the pulse and greater its amplitude. Typical wooden packages impacting a wood load platform may induce accelerations of around 40 g during carriage over rough roads. Some evidence suggests that a package restrained, using conventional restraint systems, is still capable of sufficient motions to allow bounce to occur. However, the amplitudes are likely to be more limited than for unrestrained packages.

3.3 As large vertical motions of the load platform are usually also related to large pitching motions, the payload is likely to experience angular in addition to translational motions, which result in different impact orientations and hence severities. Even where no vehicle pitch occurs, any asymmetry of the package centre of gravity is likely to result in angular motions of the package prior to impact.

3.4 The shocks arising from bounce and jostle appear as short duration transients usually with a specific sense. The durations of the transients are likely to be markedly shorter than those occurring directly from the road surface, which have a duration related mainly to the suspension frequency and probably of greater amplitude. The occurrence rate will depend upon the road surface and vehicle motions.

3.5 For loose or lightly restrained materiel a well designed protection system (or container) should significantly attenuate the majority of the effects of the shocks arising from bounce and jostle. Moreover, the amplitude of the transients will be less severe than those likely to occur as a result of any mis-handling such as being dropped. However, the payload may experience a number of such transients, in the region 100-10000, giving rise to possibly medium cycle fatigue failure conditions.

4. 2/1-PACKAGING PARAMETERS

4.1 The majority of materiel intended to encounter the transportation environment will be contained within some form of protection or packaging. Some structural interaction may occur between the materiel and its packaging. However, when considering the possible damaging effects it has been assumed that this interaction will not induce additional materiel failure modes. This assumption is not unreasonable for well designed protection or packaging. Four useful basic packaging principles are:

a. The packaging should not open up and spill its contents, or collapse on its contents.

b. Articles within the packaging should be held and immobilised to prevent movement and impact damage.

c. The means of immobilising the contents inside the packaging must transmit forces to the strongest part of the packaged items.

d. The inside of the packaging must be designed to cushion and distribute impact forces over the maximum surface area of the contents, and possess “yield qualities” to increase declaration time should they break loose from their restraints.

5. VEHICLE ACCELERATIONS

5.1 During road transportation, accelerations arising from vehicle operation are experienced by the payload. Generally, these accelerations are low compared to those experienced during other phases of deployment and can be classed as "quasi-static". Typical values associated with payload restraint loads are listed below.

a. Forward 1.0 g

b. Aft 0.5 g

c. Upwards 0.5 g (excluding gravity)

d. Downward 0.5 g (excluding gravity)

e. Transverse 0.5 g

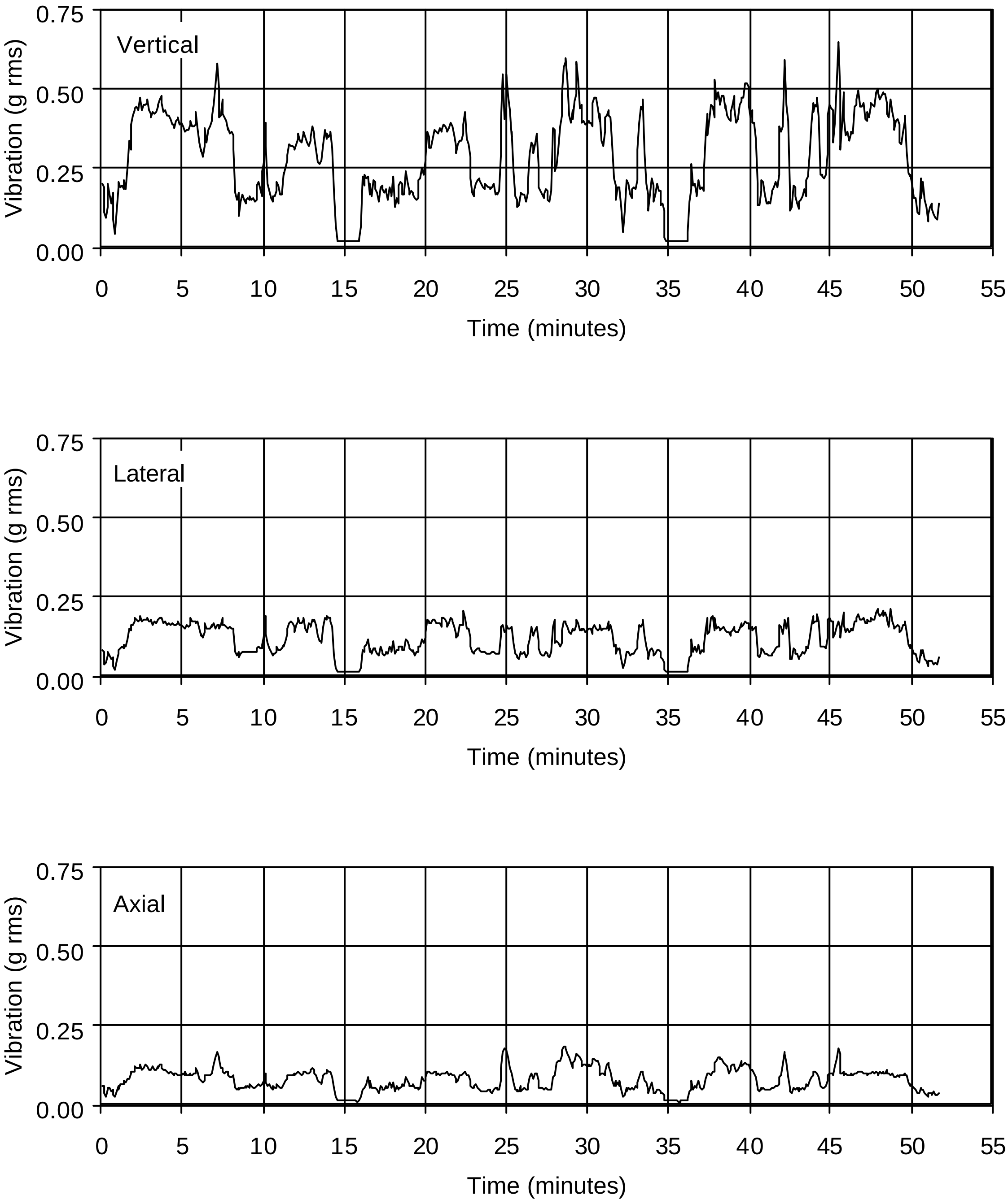


Figure 1 - Vibration (g rms) from a Bedford 4x4 truck on a good quality road

Note: 1. *Vibration measured on the vehicle load bed over the rear axle*
2. *Vehicle loaded to approximately 50% capacity by mass*
3. *Payload secured*

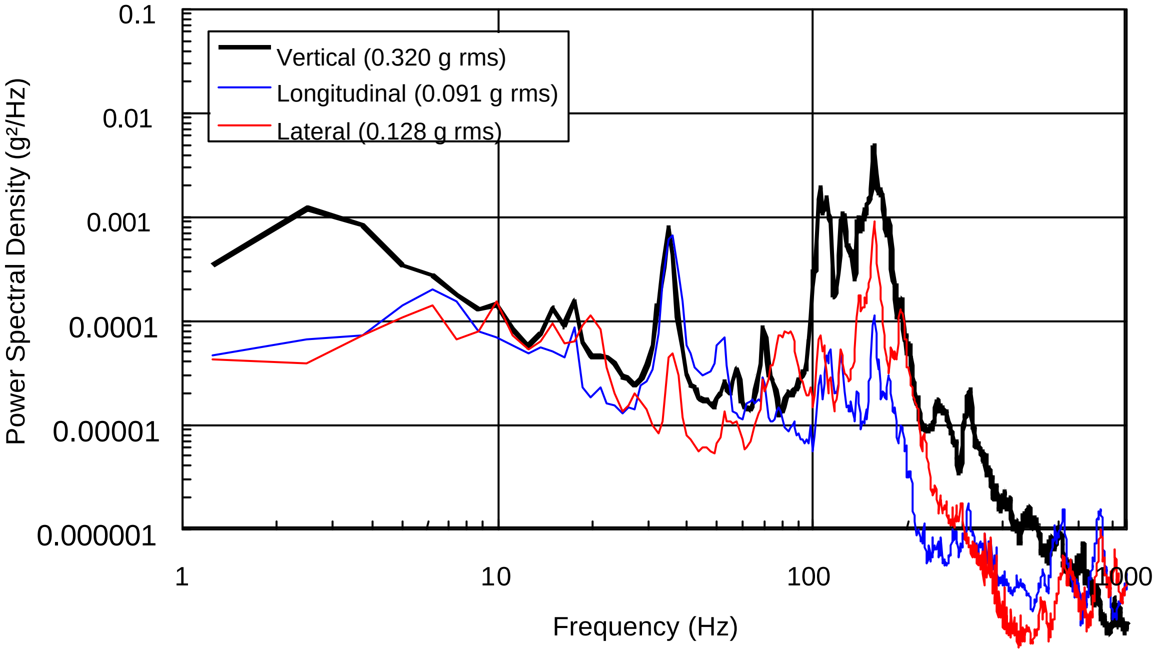


Figure 2 - Mean spectra from a Bedford 4x4 truck on a good quality road

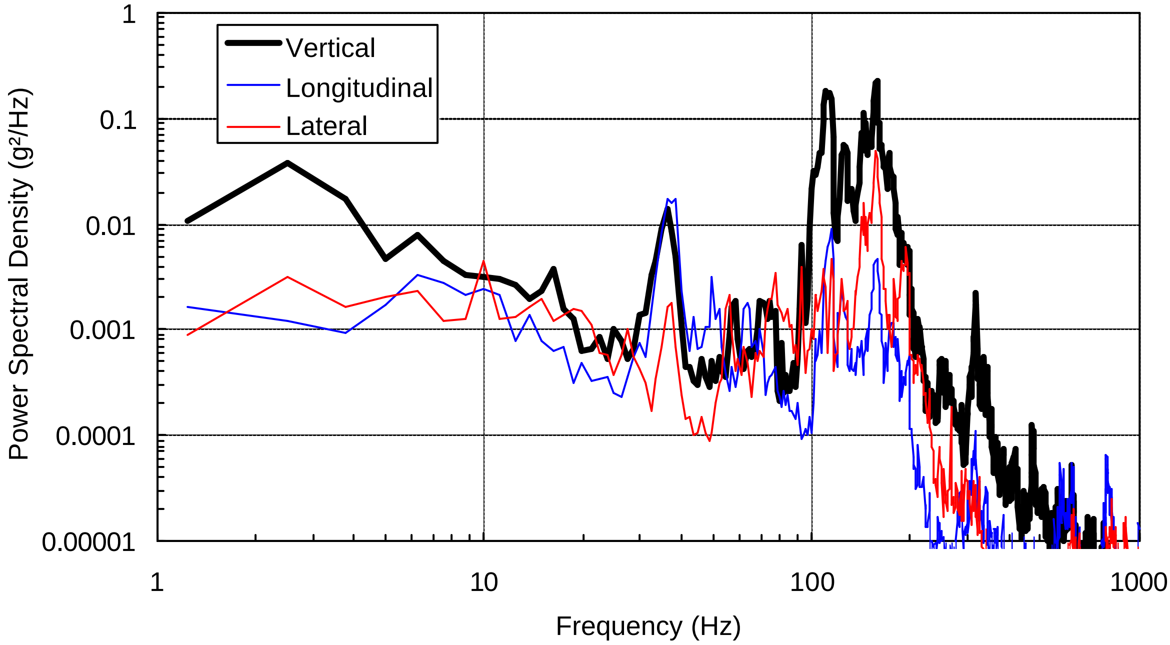


Figure 3 - Peak-hold spectra from a Bedford 4x4 truck on a good quality road

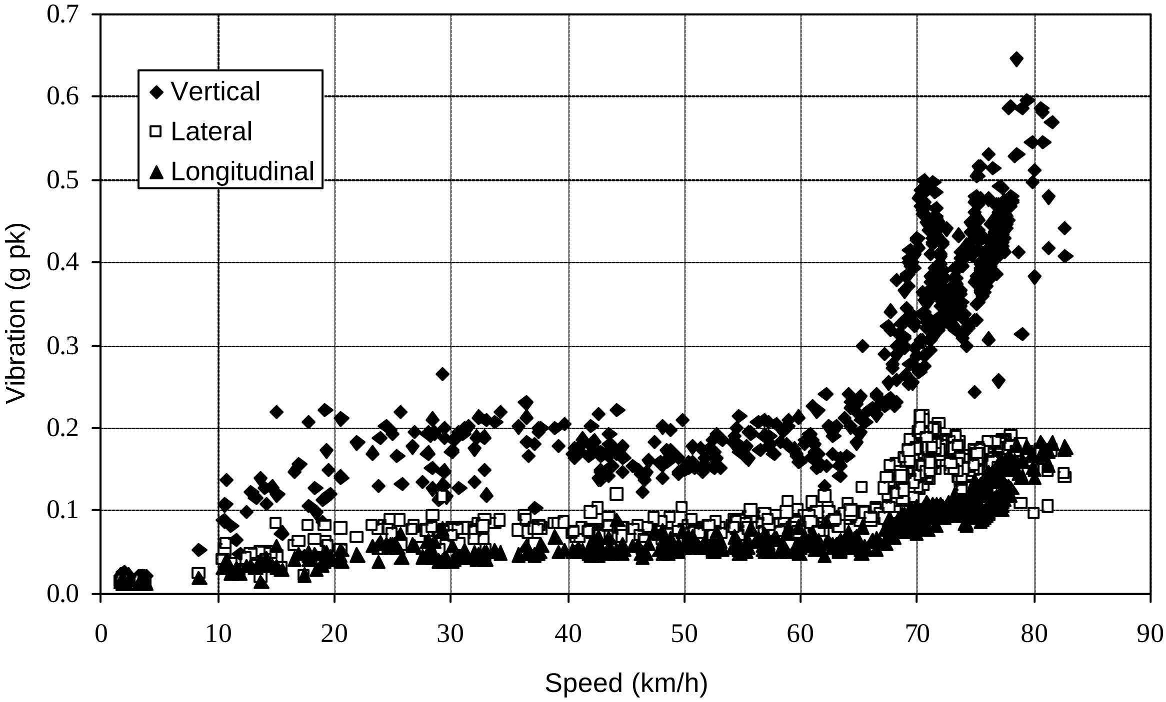


Figure 4 - Effect of road speed on block rms values from a Bedford 4x4 truck on a good quality road

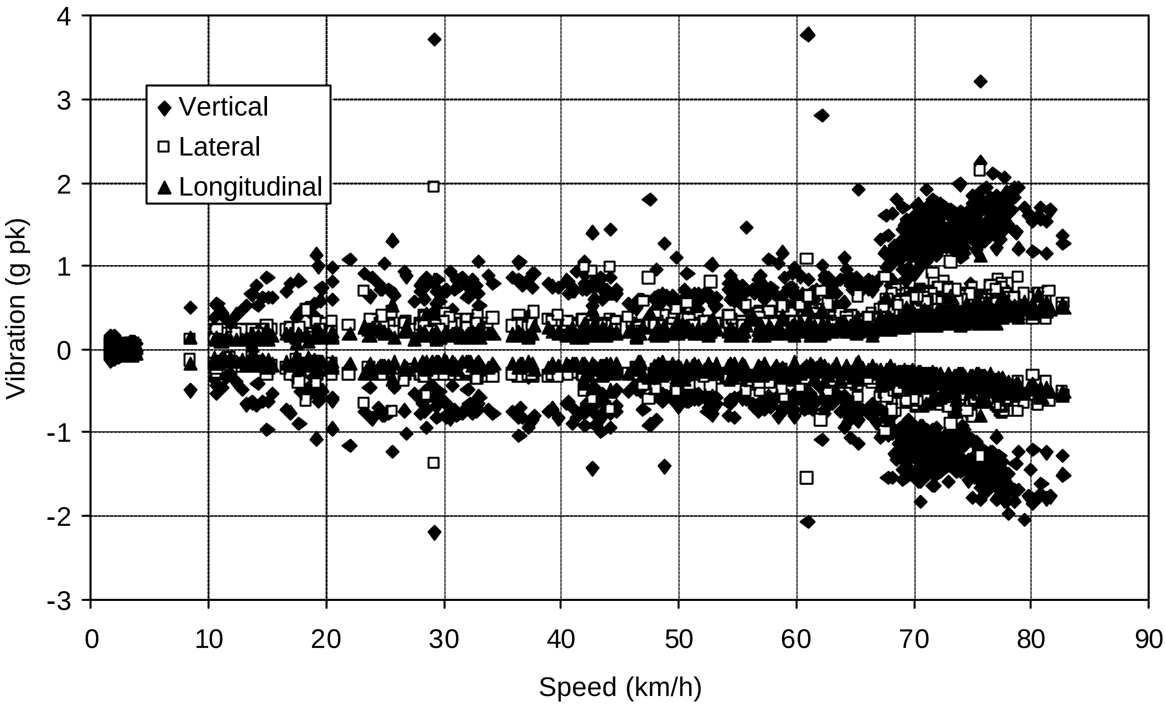


Figure 5 - Effect of road speed on block peak values from a Bedford 4x4 truck on a good quality road

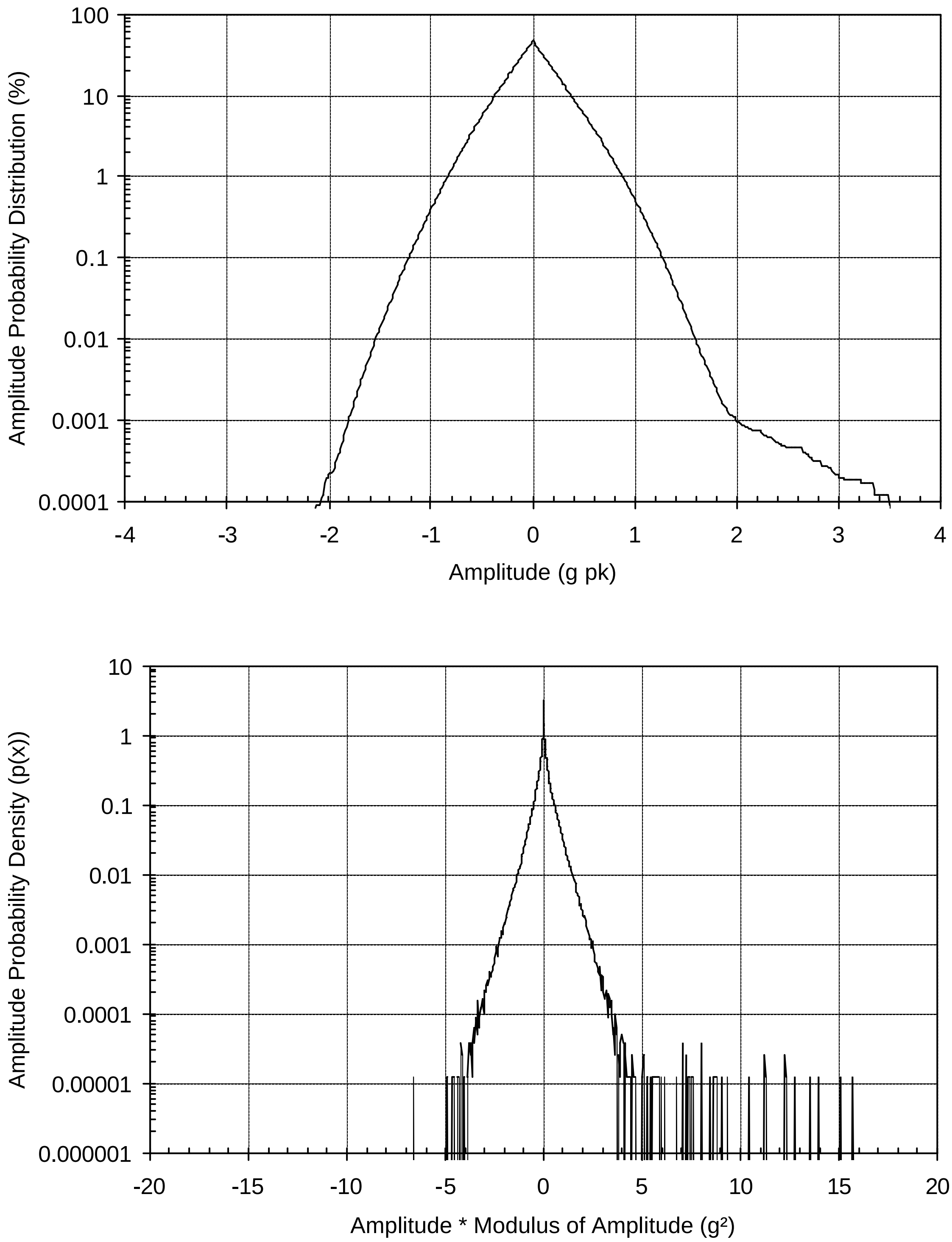


Figure 6 - Probability functions from a Bedford 4x4 truck on a good quality road

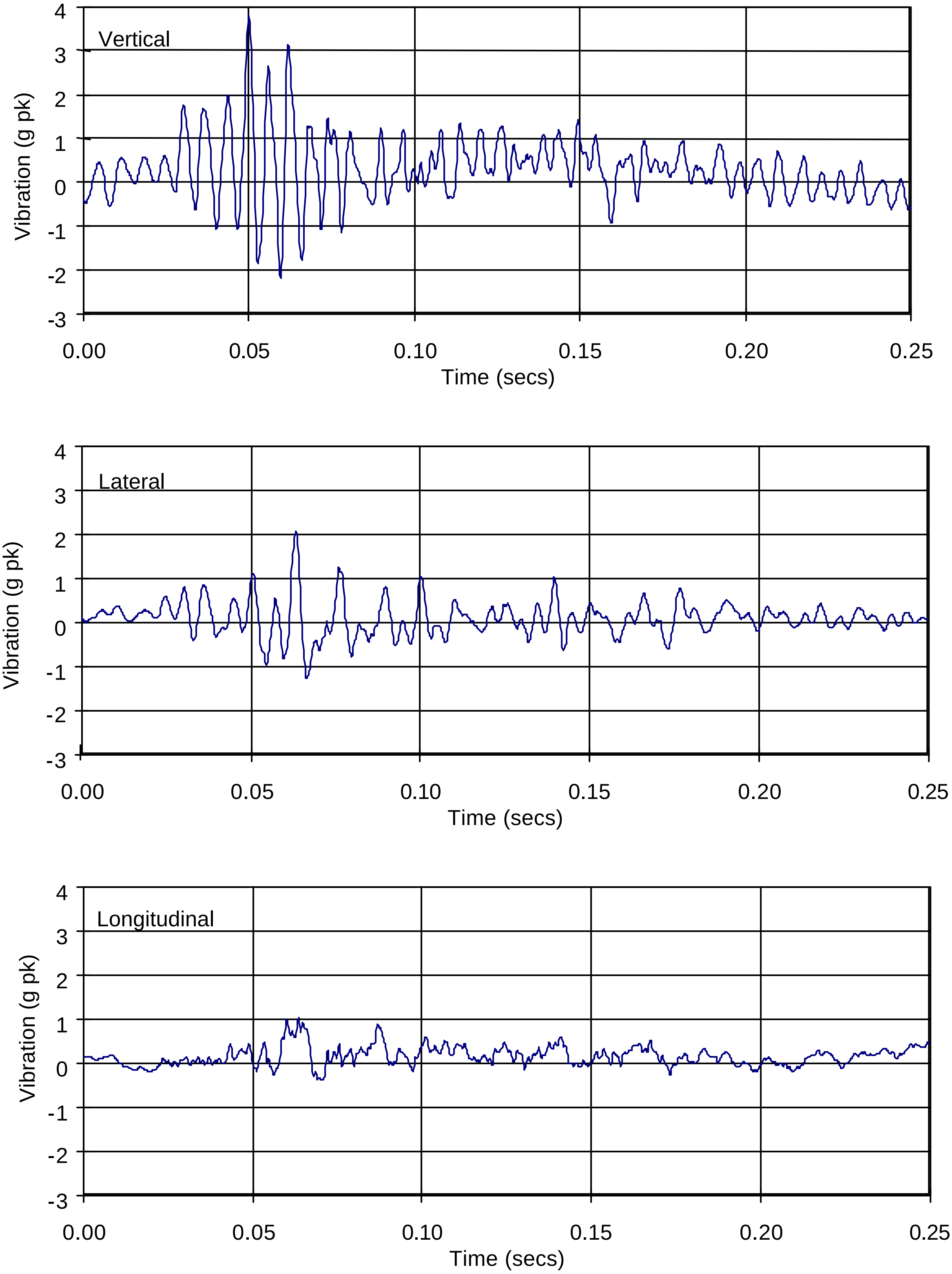


Figure 7 - Transient responses experienced on a Bedford 4x4 truck on a good quality road

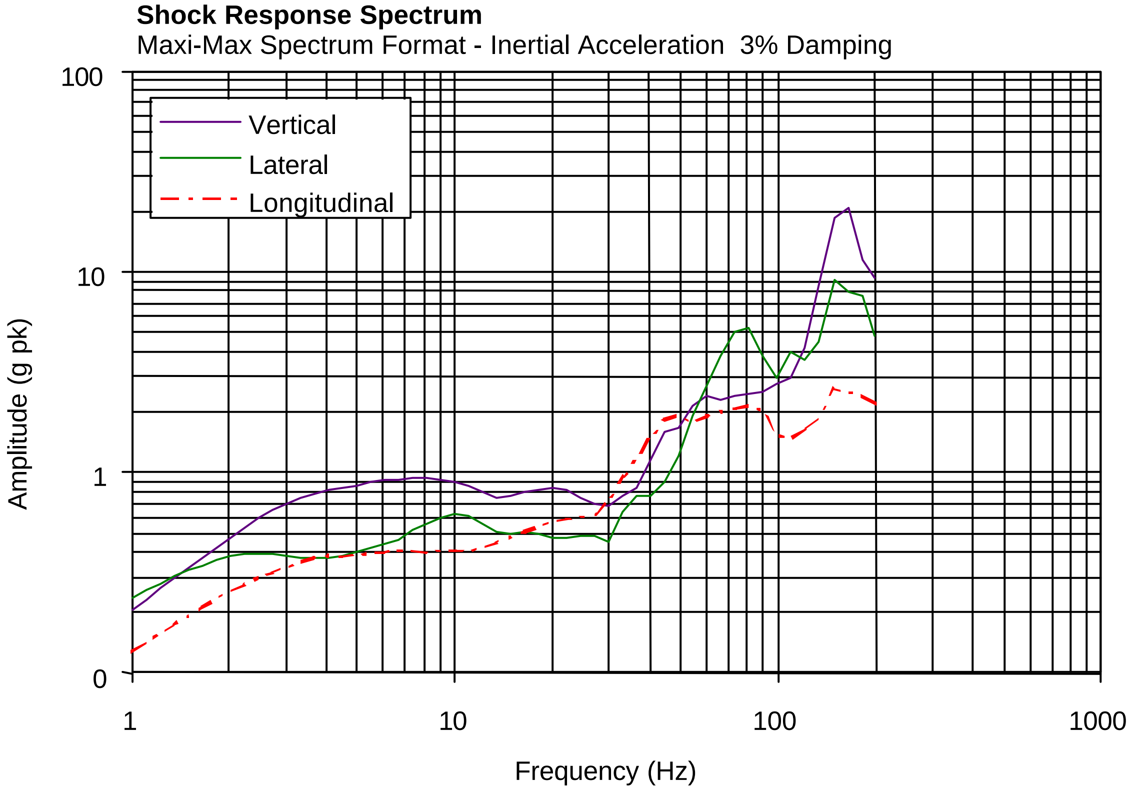


Figure 8 -Shock response spectra of a transient experienced on a Bedford 4x4 truck on a good quality road

PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS WHEN MATERIEL IS CARRIED AS RESTRAINED CARGO

A.1 Road Surface Induced

A.1.1 General: Dynamic responses of payloads originate from the interaction of the vehicle road wheels with the road surface. The mechanism producing these motions is dependent upon the irregularities of the road surface, vehicle velocity as well as wheel and suspension characteristics. In addition, the response of the payload to this form of vehicle excitation will be modified by the vehicle dynamic characteristics, the payload location on the vehicle and also vehicle wheel geometry. The latter is of importance because not only does this form of excitation occur at all road wheels but a high degree of correlation can exist between the motions originating at each wheel.

A.1.2 Road Surface Quality: Measurements undertaken in recent years indicate that, in broad terms, road type has some effects on the amplitude of vibrations. However, this variability may not be as significant as the effects of variations in vehicle speed arising from the use of different road types. Road type does appear to have an effect on the amplitude distribution of the transient motions with the lower class roads generally producing a larger amplitude spread. Long measurement periods (several hours) on public roads, suggests that the continuous excitations (normally called the vibrations) are very broadly gaussian distributed although not necessarily with a stationary variance. Moreover, on to this distribution is superimposed the effects of the transient excitations (bumps, pot holes etc).

A.1.3 Velocity Effects: Vehicle velocity appears to be one of the most predominant parameters effecting the severity of payload dynamic responses arising from road surface. An approximate relationship between the root mean square of payload response and vehicle velocity has been noted in some instances. Variations in acceleration root mean square values during a typical journey are shown in Figure 1 of this sub-section. These are shown plotted against vehicle velocity in Figure 5 of this sub-section.

A.1.4 Vehicle Dynamics: Both the continuous and transient excitations, induced by road surface effects, are modified by the vehicle dynamics. The main modifier is the dynamic characteristics of the vehicle suspension system. The effects of the suspension system are usually to attenuate the higher frequency (>20 Hz) excitations and amplify the lower frequencies (in a nonlinear fashion), particularly at the vehicle suspension modes (typically 4-10 Hz). In some cases the suspension modes dominate the payload responses to the extent that superficial inspection of the responses suggests an almost periodic response (although closer inspection usually indicates a Rayleigh distribution) of amplitude.

A.1.5 Vehicle Loading Configuration: The mass of the total payload carried by a vehicle will affect its responses. In general, the lower the total payload mass, the greater the amplitude of responses. This effect is accentuated beyond that expected from ordinary mass loading considerations because of the non-linear nature of most suspension systems.

A.1.6 Location on Vehicle: The dynamic response experienced by a payload will depend upon its location on the vehicle. There are several rules of thumb which are often found to be applicable, although not necessarily for every vehicle and loading condition. For a fixed chassis vehicle the worst case vertical motions are usually over the rear axles. For an articulated vehicle vertical motions may be particularly significant both above the rear trailer axles and above the fifth wheel. If air suspension is fitted to the trailer the latter may prove to be the worst case location.

A.1.7 Wheelbase Geometry: The dynamic response of a vehicle may be influenced by its wheelbase geometry, ie: the excitation from the road surface is not independent at each road wheel and may be highly correlated (with a different correlation at each wheel). The effects of correlation on payload response will depend upon the location and number of road wheels. It is unlikely that this effect will be significant for small base area payloads. However, for payloads with a base area which is significant in proportion to the size of the vehicle, the degree of correlation may have to be considered when setting test severities.

A.2 Engine and Transmission Induced

The excitations arising from engine and transmission sources are, as would be expected, predominantly periodic vibrations. They occur at frequencies related to engine speed and can be at least an order greater than those of the predominant vehicle/suspension modes. Unless the payload is located close to the engine/transmission system the vibrations arising from this source are unlikely to be particularly significant.

A.3 Aerodynamic Induced

Whilst vibrations can be induced from aerodynamic sources it is unlikely these will produce any appreciable payload response unless it is exceptionally “microphonic”. The excitations from this source are usually random in nature and are usually more noticeable at the higher frequencies. In some instances cavity resonances may be induced which appear as periodic responses. However, unlike the periodic excitations from the engine and transmission, their frequency does not vary significantly with vehicle or engine speed.

SUB-SECTION 2/2 - RAIL TRANSPORTATION UP TO FORWARD BASE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during rail transportation between manufacturing sites and forward storage bases. The sources and characteristics of the mechanical environments are presented and advice is given on potential damaging effects.

1.2 Although the information contained in this sub-section relates mainly to payloads transported on the UK rail network, the ride characteristics of mainland European and North American trains are largely similar to those in the UK. The dynamic conditions produced by five UK services are discussed in Annex A.

1.3 It is unlikely that loose coupled wagons would now be used for transporting materiel. Current practice is to use only fully braked, tight coupled trains. Hence, the data quoted may be regarded as “worst case” for rail systems.

1.4 The traditional rail vehicle has two axles, a simple suspension and a wheelbase of around 3m in the UK compared to 6m in mainland Europe. This class of vehicle is limited to around 72 km/h (45 mph) and may be used extensively on the wagon load service. Bogie vehicles offer a generally superior ride performance along with the ability to carry longer and heavier loads. In more recent years improved suspensions for longer wheelbase four wheel vehicles have been designed to allow higher speeds. To meet the need for very low vibration levels at higher speeds, services are available that use vehicles with superior ride qualities.

1.5 For the purpose of this sub-section, materiel exposed to the rail transportation environment may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to vehicle axes, with the positive longitudinal axis of the right handed axes set coinciding with the direction of normal motion (ie: forward).

1.6 The dynamic environment experienced by a payload transported by rail can be considered to consist of the continuous excitations which arise during motion along the track and the transient excitations which mainly arise during marshalling (shunting operations) or switching.

2. MOTION ALONG THE TRACK

2.1 The dynamic environment experienced by a payload during motion along the track is relatively benign. In nearly all circumstances these motions will be encompassed by those of road transportation. Most payloads transported by rail also require clearance for road transportation.

2.2 The major factors influencing the severity and characteristics of the vibration environment experienced by a payload transported by a rail vehicle are track condition, vehicle speed, vehicle loading condition and vehicle type (running gear, suspension, wheelbase etc). The vehicle response to track imperfections is broadly of a random nature. An important spectral peak is due to wagons passing over sleepers, which when spaced at 0.7 m intervals results in frequencies of around 40 Hz at 100 km/h (62 mph). The fundamental body modes of the vehicle and its suspension system may also be apparent The vibration environment can be considered in vertical, lateral and longitudinal axes.

a. The vertical vibrations of rail vehicles, in worn condition, are the most significant giving the typical values shown in the following table:

Vehicle		Vibration		
Type	Speed km/h & (mph)	Mean (g)	Max (g)	Freq (Hz)
Freightliner	120(75)	0.25	0.8	3-4
4 Wheel-simple	72(45)	0.45	1.6	2-6
4 Wheel-advanced	120(75)	0.15	0.75	2-4

b. The typical vibrations, in the lateral direction, of a worn vehicle are:

Vehicle		Vibration		
Type	Speed km/h & (mph)	Mean (g)	Max (g)	Freq (Hz)
Freightliner	120(75)	0.2	0.45	3-5
4 Wheel-simple	72(45)	0.25	1.0	1-2
4 Wheel-advanced	120(75)	0.1	0.5	0.5-2

c. The longitudinal vibrations are usually insignificant, typical values being ±0.15 g at 10Hz.

2.3 During transportation minor shocks can occur due to traction, braking and gradient effects. In such cases the shock magnitude is generally determined by train coupling and braking conditions. Vehicles may be equipped with air or vacuum brakes, or no brakes at all. Coupling between wagons may be either “tight”, which ensures buffers are in contact and limits longitudinal movement, or “loose”, which leaves a gap and permits longitudinal movement. Lightly loaded vehicles may experience accelerations approximately twice those of well loaded vehicles. Typical maximum longitudinal accelerations are;

Tight coupled, fully braked train	0.2 g
Loose coupled, fully braked train	0.5 g
Loose coupled, unbraked or partially braked train	2.0 g

2.4 Inertia acceleration loadings for the rail transportation environment are considered insignificant compared to those from other modes of transport and handling.

3. SHUNTING AND MARSHALLING

3.1 Historically shunting shocks have been considered the most significant of mechanical rail environments. However, the use of modern rolling stock and current rail operational procedures means that the occurrence and severity of such shocks have significantly diminished. Should shunting occur, a payload can experience unique loadings, because although the amplitude of the transient may not be particularly high (when compared with operational events), the long durations involved result in essentially static loadings on the payload. This may result in permanent deformation and failure of materiel attachments, or the “bottoming out” of anti-shock mounts.

3.2 Major shocks can be incurred by heavy impact shunting manoeuvres in marshalling yards. The shock magnitude is dependent upon impact speed, buffering equipment characteristics and the total mass of the wagons involved. The effects of impacts are strongly aligned to the axes of the vehicle, the most severe occurring in the longitudinal axis.

a. Spring Buffers: At one time all wagons were equipped with spring buffering equipment which provided minimal protection for wagons and their contents at impact velocities commonly found in marshalling yards. Typically, with fully laden wagons, at impact velocities between 8 km/h (5 mph), and 15 km/h (9.3 mph), spring buffers will close solid and the effect is then of two solid bodies colliding. In addition, energy is stored in the buffers and can result in “shuttling” of vehicles as the energy is released. Longitudinal decelerations while the buffers are being compressed are not particularly high, around 1.5 g for a heavily loaded wagon and 3 g for a lightly loaded one, but once the buffers are fully compressed, shocks of up to 6 g can result on 6 m wheel base wagons and up to 15 g on traditional loose coupled (3 m wheel base) wagons.

b. Hydraulic Buffers: Hydraulic buffers are now fitted to all new wagons in order to minimise impact shocks. They are designed to give a constant retardation over their entire travel when the wagon is fully loaded. Decelerations of around 2 g for an 8 km/h (5 mph) impact velocity are typical, but this can rise to 4 g at 15 km/h (9.3 mph). The value of 4 g is typical of the maximum shock induced by a “cushioned” wagon fitted with hydraulic buffers.

3.3 Where the position of the centre of gravity of a wagon is above the buffer height there may be a vertical component of the shunting shock.

4. BOUNCE AND JOSTLE

4.1 Generally the bounce and jostle originating from rail transportation is less severe than that from road transportation. However, the mechanisms producing the motions are similar. Further, as the severities of the loose cargo test cannot easily be tailored to specific environments, little value is gained by addressing this aspect of rail transportation separately from that of road transportation.

PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 General

A.1.1 The dynamic environment experienced by a payload during rail transportation is dependant upon the type of service used. In the UK, freight is carried via five different services ie. wagon load, speedlink, train-load, freightliner and parcel.

A.2 Wagon load service

A.2.1 The wagon load service is the traditional method by which freight is carried. In recent times this service has been largely phased out and today defence materiel is unlikely to transported in this manner. The wagon load service involves goods been brought to a freight depot by road, and loaded onto wagons. These wagons are then conveyed to a marshalling yard, where they are sorted into trains of suitable length for transit to their destination or another marshalling yard. The wagons used may be of any type including short wheelbase vehicles with simple suspension (ie: those giving generally the worst vibration environment). In such cases speeds are generally low, ie. less than 72 km/h (45 mph). In marshalling yards, vehicles are sorted into different sidings by propelling them without a locomotive being attached. In certain yards, retarders may be used to help control wagon impacts. Impacts can occur between vehicles at speeds up to 24 km/h (15 mph), with a mean of 9.5 km/h (5.9 mph). Figure A1 shows the distribution of impact speeds in a typical marshalling yard. The effects on vehicle payloads of these impacts will be partly mitigated by the buffering gear.

A.3 Speedlink service

A.3.1 An advance on the wagon load service is the speedlink service. This is an express service using air-braked vehicles of modern design. The main operational difference between the speedlink and wagon load service is that speedlink is an essentially regular pattern of services. As such, whilst the wagons are loaded as in the wagon load service, they are conveyed to a point were they can be marshalled into a scheduled speedlink service. They remain coupled to the locomotive during marshalling and are thus not subjected to impacts at velocities greater than 2-3 km/h (1.2-1.9 mph).

A.4 Train-load service

A.4.1 Train-load services, also known as block or company trains, run from one origin to one destination. They may comprise any type of vehicle and are not normally marshalled at intermediate points.

A.5 Freightliner service

A.5.1 In the freightliner service, containers are collected from a customer's premises by road, conveyed to a freightliner terminal, and loaded onto purpose built air-braked wagons. These wagons may be marshalled at intermediate points but are not subject to high impact velocities.

A.6 Parcel service

A.6.1 The parcel service, for small consignments or single items uses both bogie vehicles, similar to passenger coaches, and long-wheelbase four-wheel vehicles. Re-marshalling may be involved but not loose shunting.

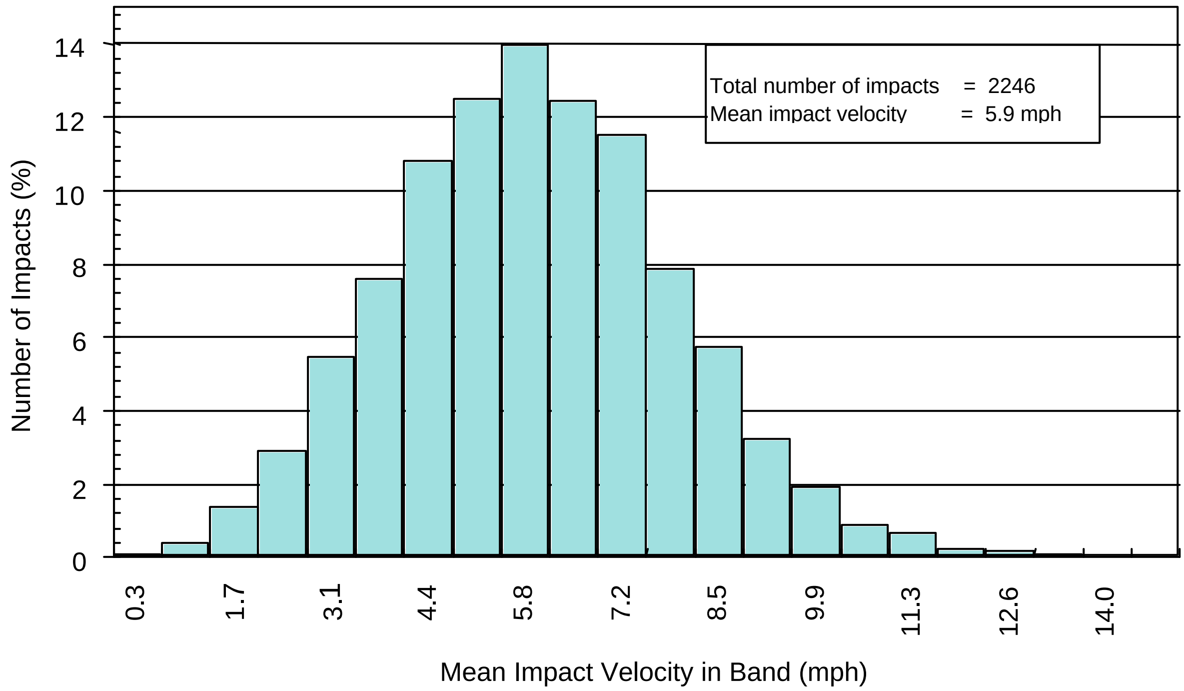


Figure A1 - Distribution of wagon impact speeds in a marshalling yard

SUB-SECTION 2/3 - AIR TRANSPORTATION UP TO FORWARD DEPOT

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during air transportation between manufacturing sites and forward storage bases. The sources and characteristics of the mechanical environments are presented and discussed, and advice is given on potential damaging effects.

1.2 The sub-section considers air transportation by fixed wing jet aircraft, fixed wing propeller aircraft and rotary wing aircraft. In general the payloads are considered to be carried internally within the aircraft. In addition, helicopter underslung payloads and air dropped payloads are addressed. The aircraft considered are those normally used for transportation purposes, but in practice the characteristics of most types of propeller aircraft and helicopters are likely to be encompassed, although transportation in high performance jet aircraft would almost certainly not be covered.

1.3 For the purpose of this sub-section, materiel exposed to the air transportation environment may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to aeroplane axes, with the positive longitudinal axis of the right handed axes set coinciding with the direction of normal motion (ie: forward).

2. FIXED WING JET AIRCRAFT

2.1 The dynamic excitations experienced by materiel carried as payload within fixed wing jet aircraft arise predominantly from aerodynamic sources, power plant sources and jet plume effects.

2.2 The vibration environments experienced by payloads carried within fixed wing jet aircraft are generally characterised as gaussian broad band random motions with superimposed periodic components possibly just discernible. The broad band random vibration arises from both jet noise and aerodynamic sources. The periodic vibrations are generated by the rotating components within the turbines and transmitted mechanically throughout the aircraft structure. In the example shown the periodic components are mainly associated with the power supply frequency.

2.3 The extent to which excitations may be generated by these sources depends upon the flight conditions. Four flight conditions are considered for illustration, namely, take-off, climb, cruise, and landing. Typical vibration severities for these conditions, using the rear engined VC10 aircraft for illustration, are shown in power spectral density format in Figure 1. Corresponding root mean square values are shown in Figure 2.

a. Take-off conditions give rise to significant vibration levels, but only for short durations. Taxiing generates low level vibration which is normally encompassed by that from take-off.

b. Significant vibration may be apparent during climb when high demand is placed upon the power plant. However, levels are unlikely to exceed those of take-off.

c. Vibration levels associated with cruise conditions are of low level mainly because the flight dynamic pressures are relatively low. Also, the effects of aircraft manoeuvres, such as turns do not produce significant vibration responses of the payload although they may produce the highest loads on restraint systems. Descent generally produces negligible levels, although if spoilers or flaps are used to provide air-braking, significant vibration at low frequencies can be experienced.

d. Landing can produce two distinct excitations: touch down, giving a transient excitation, and reverse thrust, giving a vibration excitation. Transient amplitudes levels can attain 1 g pk and can be characterised by a decaying sinusoid. In some cases (including the example shown) the transient cannot be distinguished from the vibration. Vibration during reverse thrust can exceed the levels associated with take-off, although for a shorter period.

2.4 As the dynamic environments experienced by payloads carried within fixed wing jet aircraft are benign, any potential damaging effects are unlikely to require special consideration.

3. FIXED WING PROPELLER AIRCRAFT

3.1 Vibration measured at any point on a propeller aircraft will be the sum of many sources and mechanisms. Almost all these mechanisms arise as a result of the propellers, which can generate vibration directly or produce noise which generates vibrations when it impinges on the aircraft structure. Consequently, the maximum vibration severities within the cargo bay are experienced by materiel sited in the plane of the propellers. The relative severities along the length of the fuselage are shown in Figure 3.

3.2 As the dominant source of vibration arises from the aircraft's propellers, the spectral characteristics of the environment is dominated by peaks corresponding to the blade passing frequency and its subsequent harmonics. Generally blade passing frequencies are more significant than shaft frequencies. However, the latter are still often important, especially given the low frequencies involved. The periodic motions are superimposed upon a background of broad band random vibration.

3.3 The extent to which excitations may be generated again depends upon the flight conditions. Typical vibration severities for four conditions, using the four engined, four bladed Hercules C130 propeller aircraft for illustration, are shown in power spectral density format in Figure 4. Root mean square values for these and other conditions are shown in Figure 5.

a. <u>Take-off:</u> The highest vibration severities occur during take-off as shown in Figures 4 and 5.

b. <u>Climb</u>: Significant vibration levels are generated during climb, although again, these are generally enveloped by those of take-off.

c. <u>Cruise</u>: Vibration levels during cruise are relatively low, even if the aircraft's engines are allowed to operate out of synchronisation with one another. Aircraft manoeuvres, such as turns, do not significantly increase vibration levels within the aircraft. Descent generally produces negligible levels.

d. <u>Landing</u>: Vibration during reverse thrust can equal the levels associated with take-off, although for shorter periods. Transient response levels during landing can attain 2 g pk and be characterised by a decaying sinusoid. Typical landing shocks are shown in Figure 6.

3.4 The vibration responses, experienced by a payload at the blade passing frequency and its subsequent harmonics can be significant. In particular, the blade passing frequency can often be quite close to the internal mounting frequency of materiel within their containers.

3.5 Many environmental descriptions of transportation severities in propeller aircraft indicate that the accelerations occurring at the blade passing frequency are the most significant. This is not always the case. The second or third harmonic of blade passing frequency may be the most significant in some cases.

3.6 The vibration characteristics for fixed wing propeller aircraft are similar to, but usually less severe than, those of helicopter carriage. However, it should be noted that the blade passing frequency on fixed wing propeller aircraft is likely to be significantly higher than that on helicopters. As such, the fixed wing propeller vibration environment is unlikely to be encompassed within that experienced by materiel transported in helicopters.

4. ROTARY WING AIRCRAFT

4.1 The dominant source of vibration arises from the action of the helicopter's main rotor blades and gearboxes. Consequently, a typical helicopter vibration spectrum is characterised by peaks at the main rotor blade passing frequency and its subsequent harmonics. For single rotor helicopters, components at frequencies associated with the tail rotor may be also be noted. For dual rotor helicopters, such as Chinook, significant responses occur at twice the blade passing frequency due to interaction between the two sets of blades. In all cases the peaks in response spectra are superimposed against a background of broad band random vibration.

4.2 The extent to which excitations may be generated again depends upon the flight conditions. Typical vibration severities for four conditions, using the Chinook dual rotor helicopter for illustration, are shown in power spectral density format in Figure 7. Root mean square values for these and other conditions are shown in Figure 8.

a. Vibration severity during take-off and hover (Figure 7b) is low and almost always encompassed by the levels encountered during flight. Vibration during taxi, when applicable, is also low.

b. Under straight and level flight conditions vibration severity is mainly dependent upon forward speed, although not linearly related to it. A typical acceleration spectral density for straight and level flight is shown in Figure 7d where the contributions from shaft and the first four blade passing frequencies are clearly visible.

c. Transient conditions, such as transition to hover (Figure 7a), are likely to generate high vibration levels, but for only a few seconds. Maximum power climbs can also generate high vibration over several minutes.

4.3 The variation of vibration severity along the fuselage of a Chinook helicopter is indicated in Figure 9.

4.4 As the blade passing frequency may be less than the internal mounting frequency of materiel within its containers, the mounting arrangements may offer little protection against this vibration environment.

5. UNDERSLUNG PAYLOADS.

5.1 Materiel may be underslung from helicopters, either directly in nets, or within containers. In either case, the dynamic environment experienced by the payload is largely independent of that of the carriage helicopter. Vibration responses tend to be broad band in character and of very low amplitude. Excitation is mainly due to aerodynamic forces such as atmospheric turbulence.

5.2 The pick-up of the payload can give rise to transients of a decaying sinusoid nature. Response amplitudes are generally enveloped by those of set-down on land which can typically attain a peak amplitude of 4 g. Measured data indicate that impact velocities of up to 2.5 m/s are possible. Typical shock responses during set-down on land are shown in Figure 10.

5.3 The high set-down velocities that can occur on naval vessels whilst at sea, will result in severe transient response amplitudes. Measured data are not available for these conditions.

5.4 For some suspension arrangements, usually multi-cable suspension systems, rigid body dynamic interaction between the helicopter and payload can occur which can produce very high loads on the attachment cables (and any container if connected directly).

5.5 The potential damage arising from carriage as underslung arises mainly from impact on set-down. However, for set-down on land the levels are generally similar to general handling loadings. Only for large equipment are set-down shock loadings on land likely to exceed those for handling. The most likely damage mechanism is that of materiel moving excessively within its packaging, such that the capabilities of the cushioning material are exceeded.

6. AIR DROPPED PAYLOADS

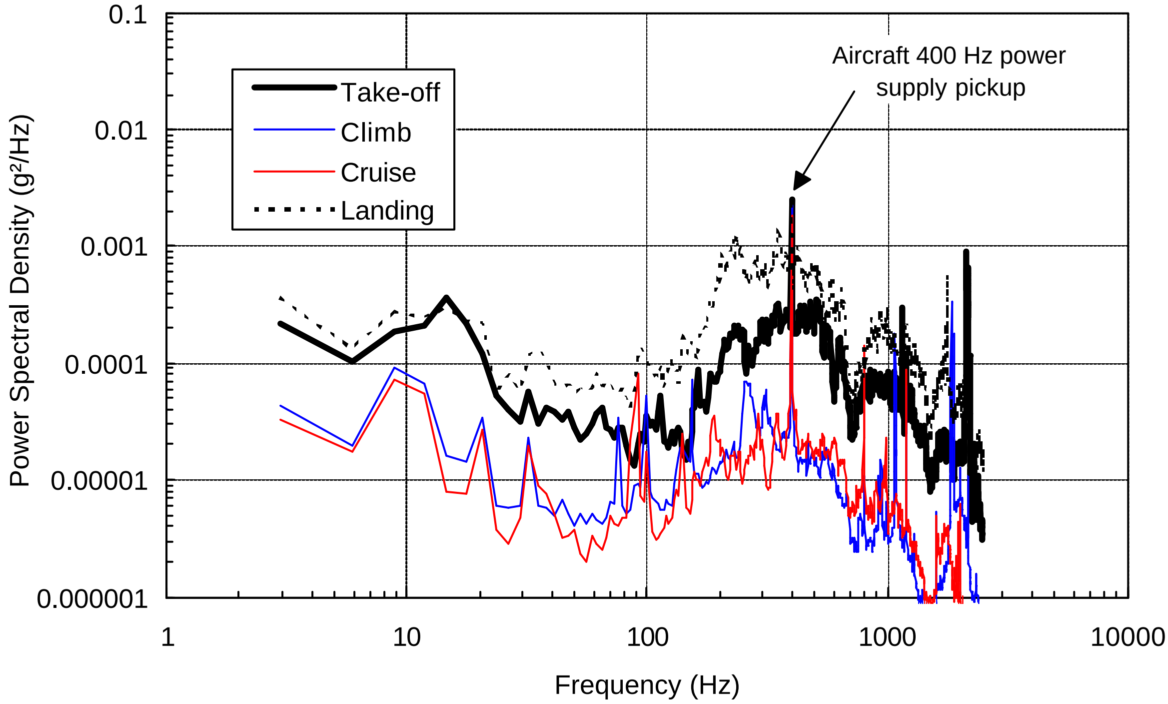
6.1 Air dropped payloads will also experience additional transients arising from parachute deployment and during impact. Air dropped payloads are usually arranged in a manner so as to mitigate the effects of impact. This mitigation often takes the form of shock absorbers intended to modify the impact transient to one with a longer duration and lower amplitude.

6.2 Severe impact conditions may be experienced by payloads intended for low level drops. Measured data are not available for these conditions.

6.3 Air dropped payloads should be capable of withstanding impact velocities up to 9 m/s (30 ft/s). Those intended for low level drops, may be required to withstand higher impact velocities.

7. STEADY STATE ACCELERATION

7.1 During all forms of air transportation quasi-static accelerations are experienced during flight. However, these are usually less than those experienced during other phases of deployment.



Note: All data from the rear of the aircraft and in the vertical axis.

Figure 1 - Vibration spectra from a VC10 jet transport aircraft

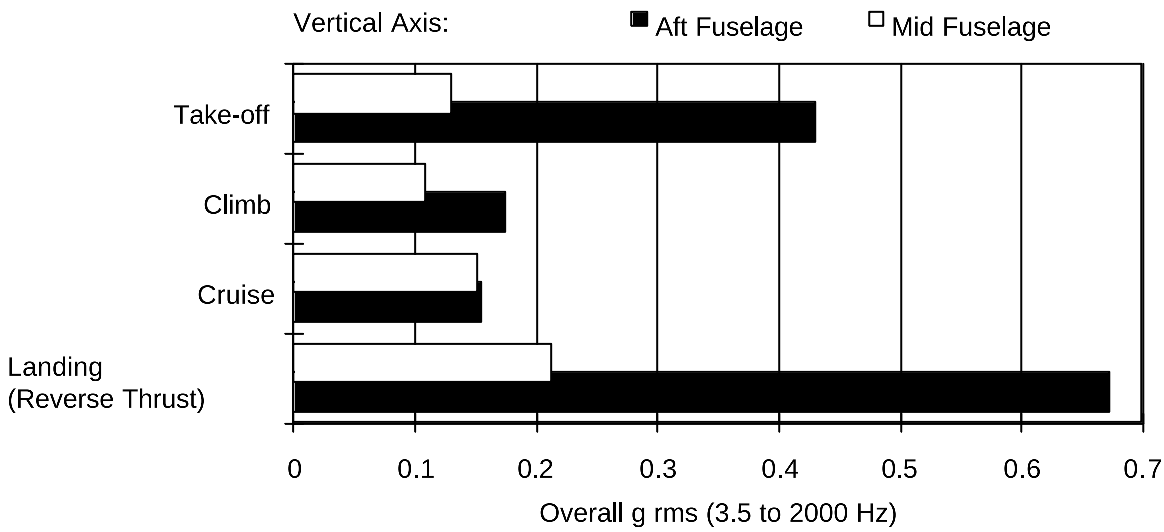
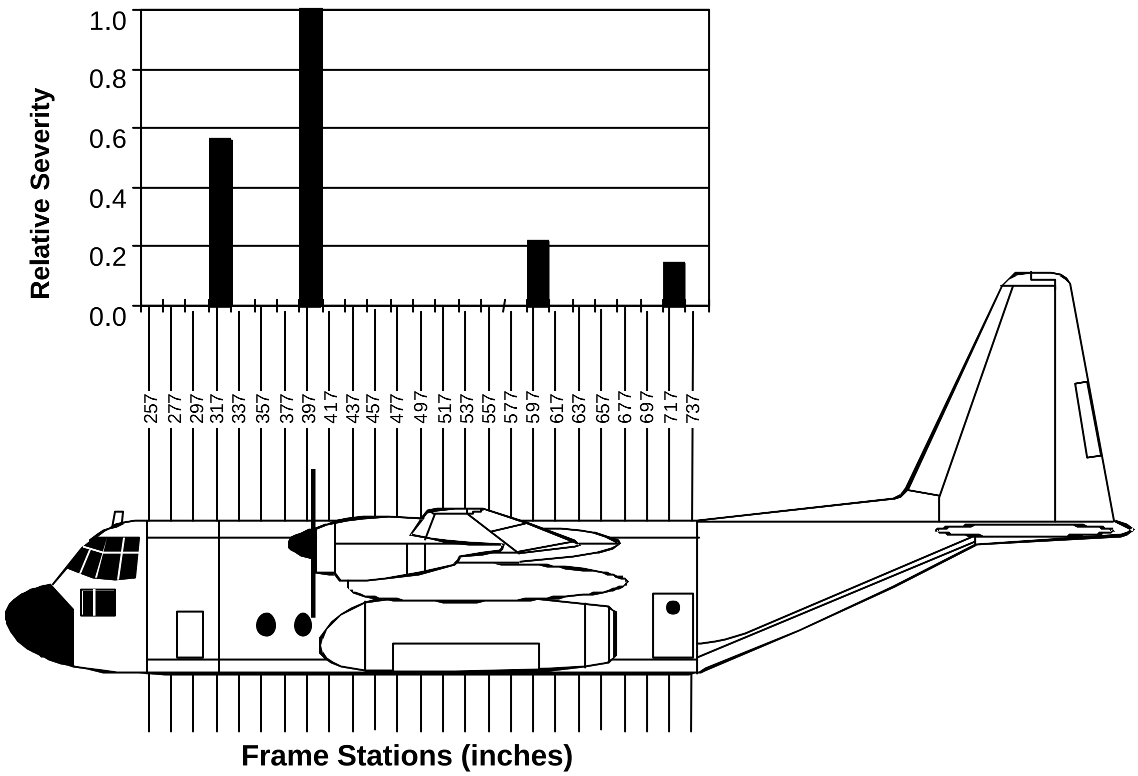
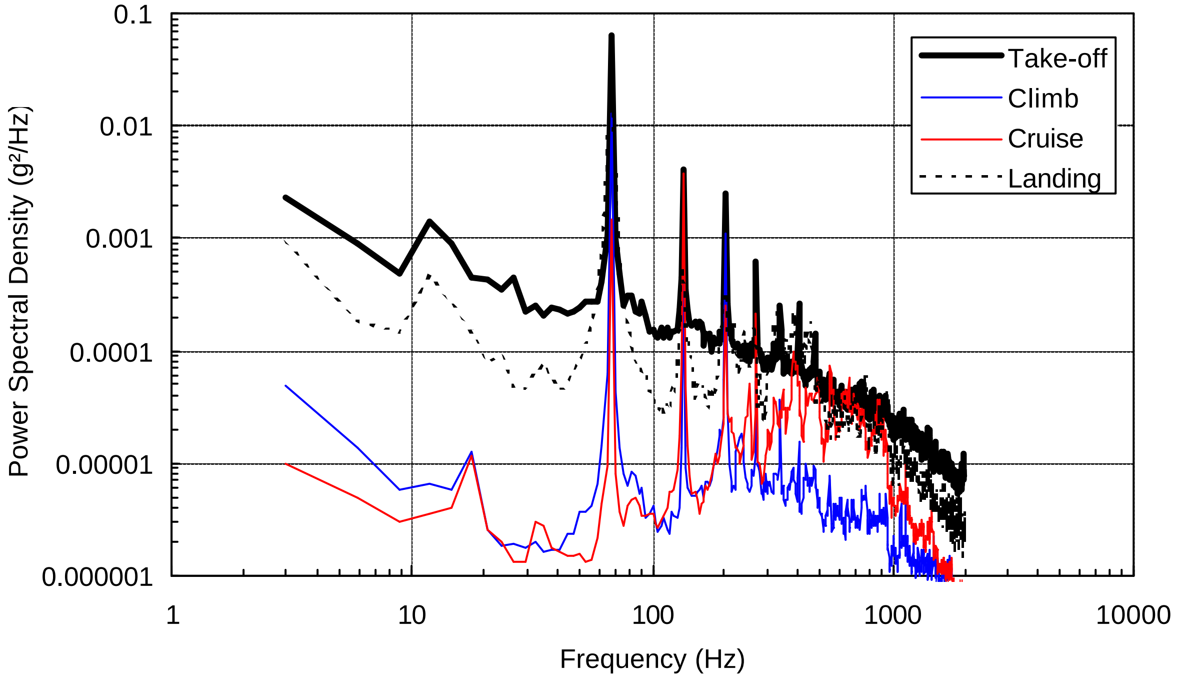


Figure 2 - Variations of vibration severity in various manoeuvres and at two locations



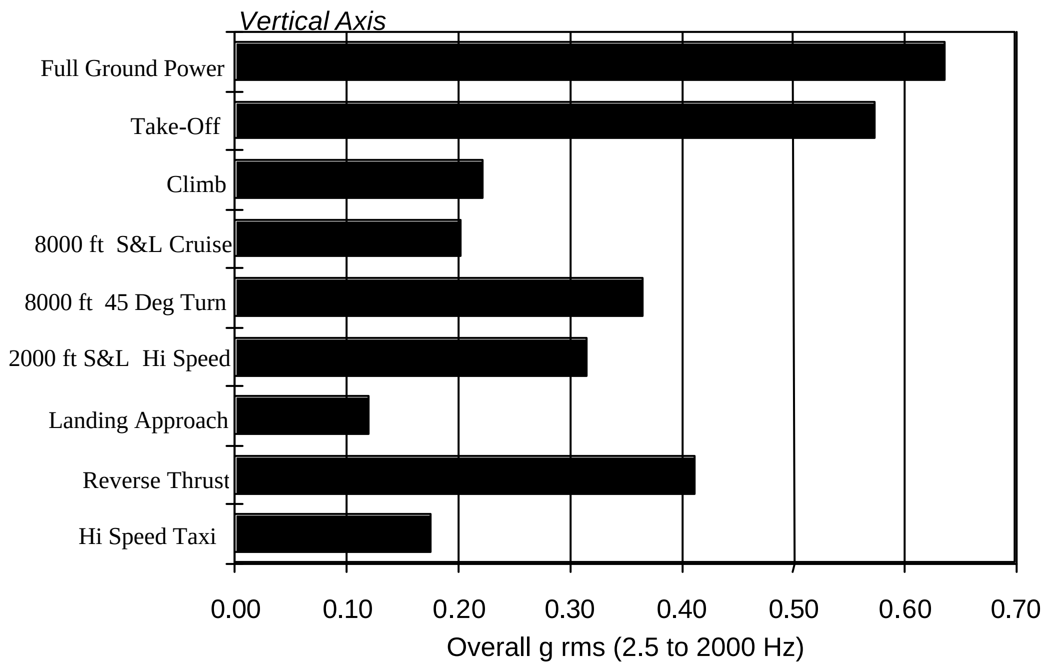
Note: All data measured in the vertical axis.

Figure 3 - Variations of vibration severity along the fuselage of a C130 aircraft



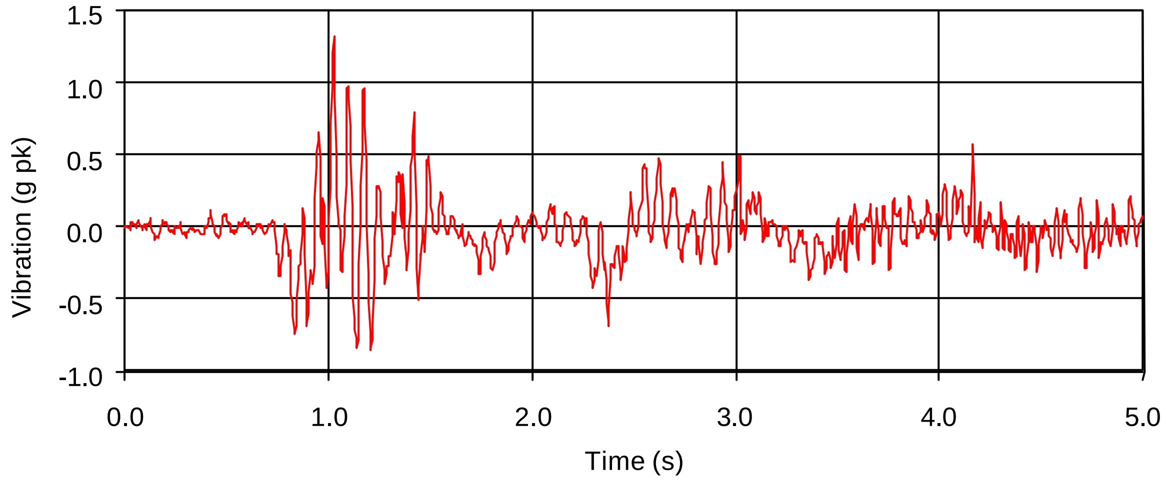
Note: All data from the plane of the propellers and in the vertical axis.

Figure 4 - Vibration spectra from a C130 Hercules turbo-prop transport aircraft

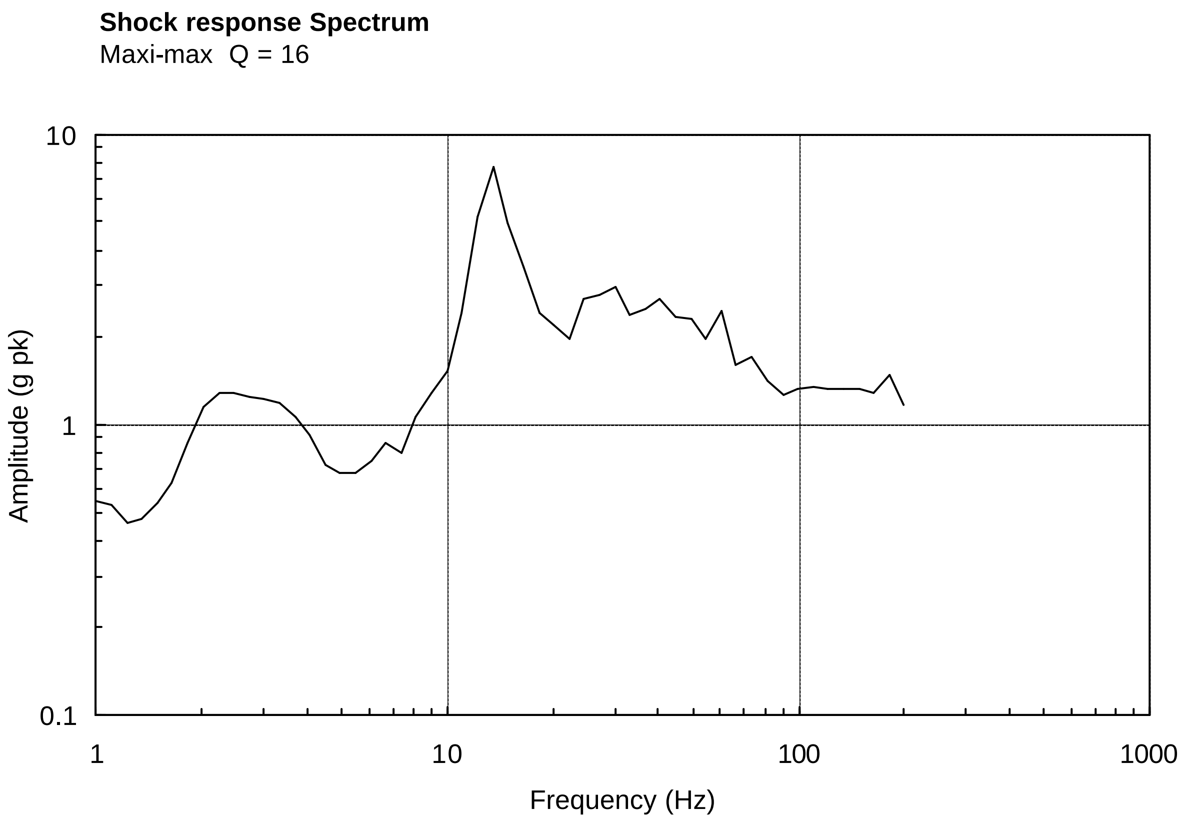


Note: All data from the plane of the propellers.

Figure 5 - Variation of vibration severity in various manoeuvres for a Hercules C130 turbo-prop aircraft

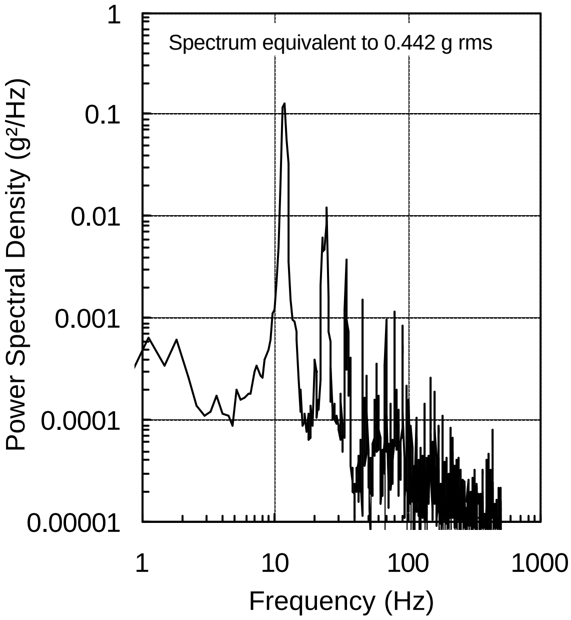


a. Shock history

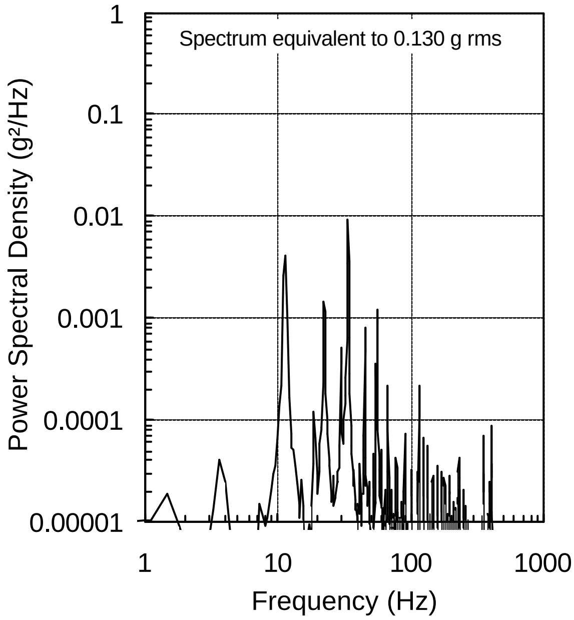


b. Shock response spectrum

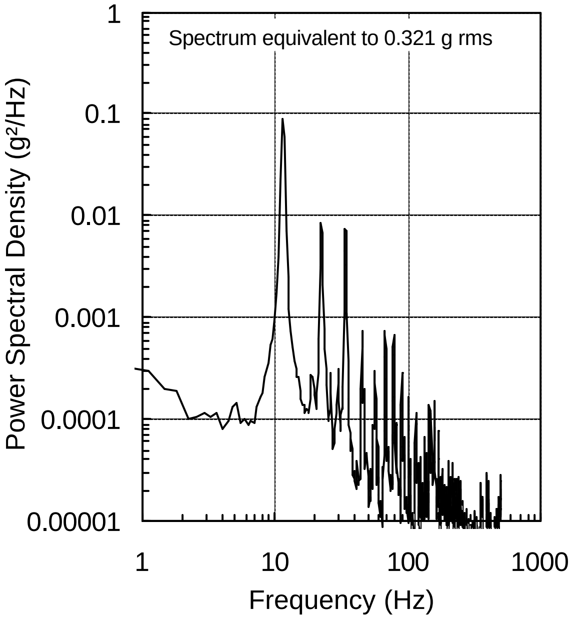
Figure 6- Propeller transport aircraft tactical landing shock



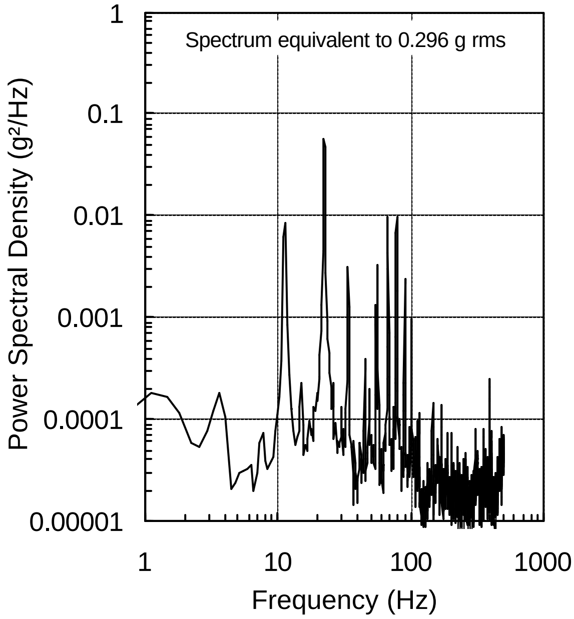
a. Transition to hover



b. Hover



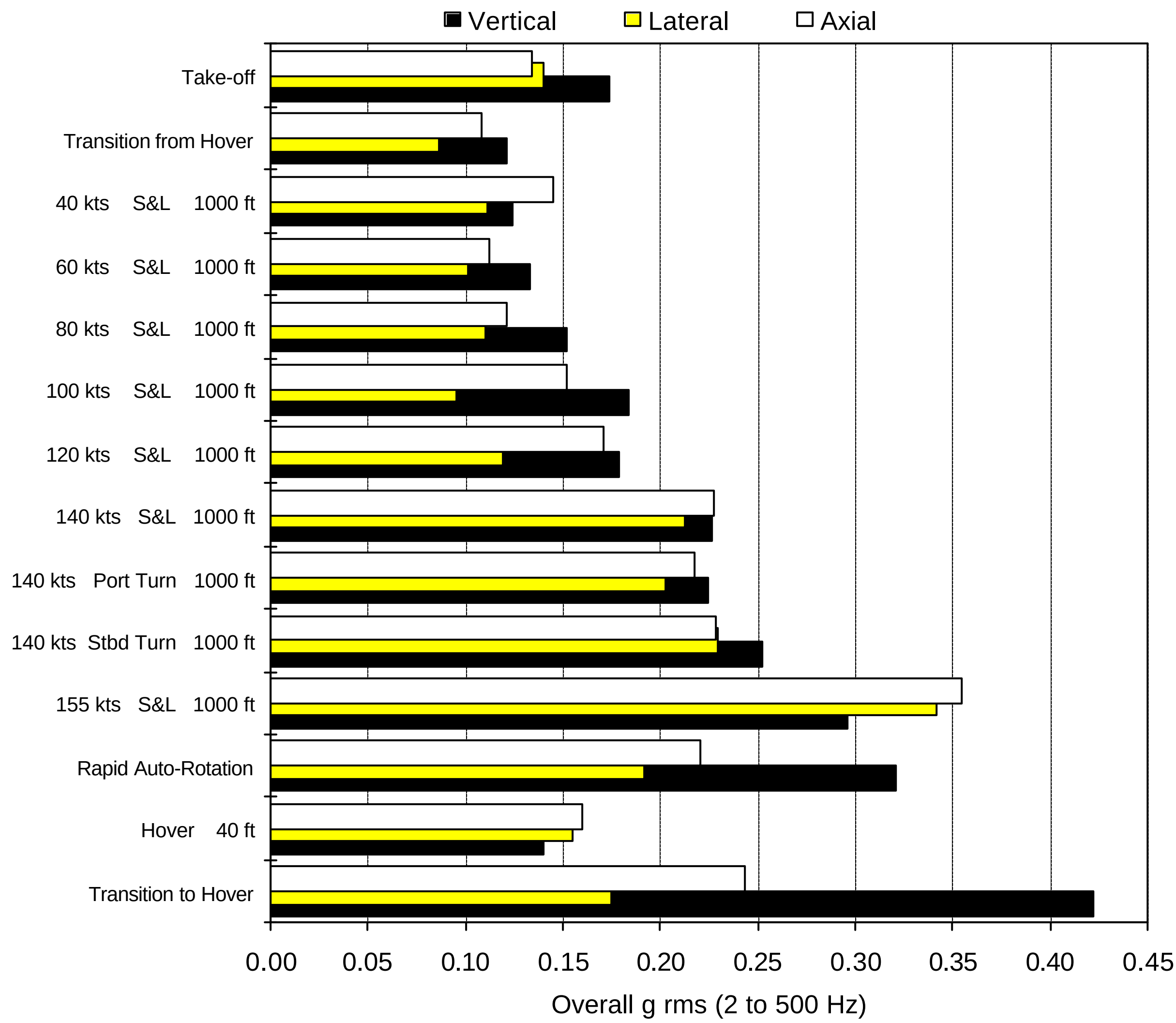
c. Recovery from auto-rotation



d. 155 kts Straight and level

<u>*Note:*</u> *All data measured in the vertical axis at Frame Number E160 (see Figure 9)*

Figure 7: Vibration responses from a Chinook HC Mk2 transport helicopter during various flight conditions



Note: All data measured at Frame Number E160 (Stbd) at floor level (see Figure 9)

Figure 8 - Variation of vibration severity in various flight conditions for a Chinook HC Mk2 helicopter

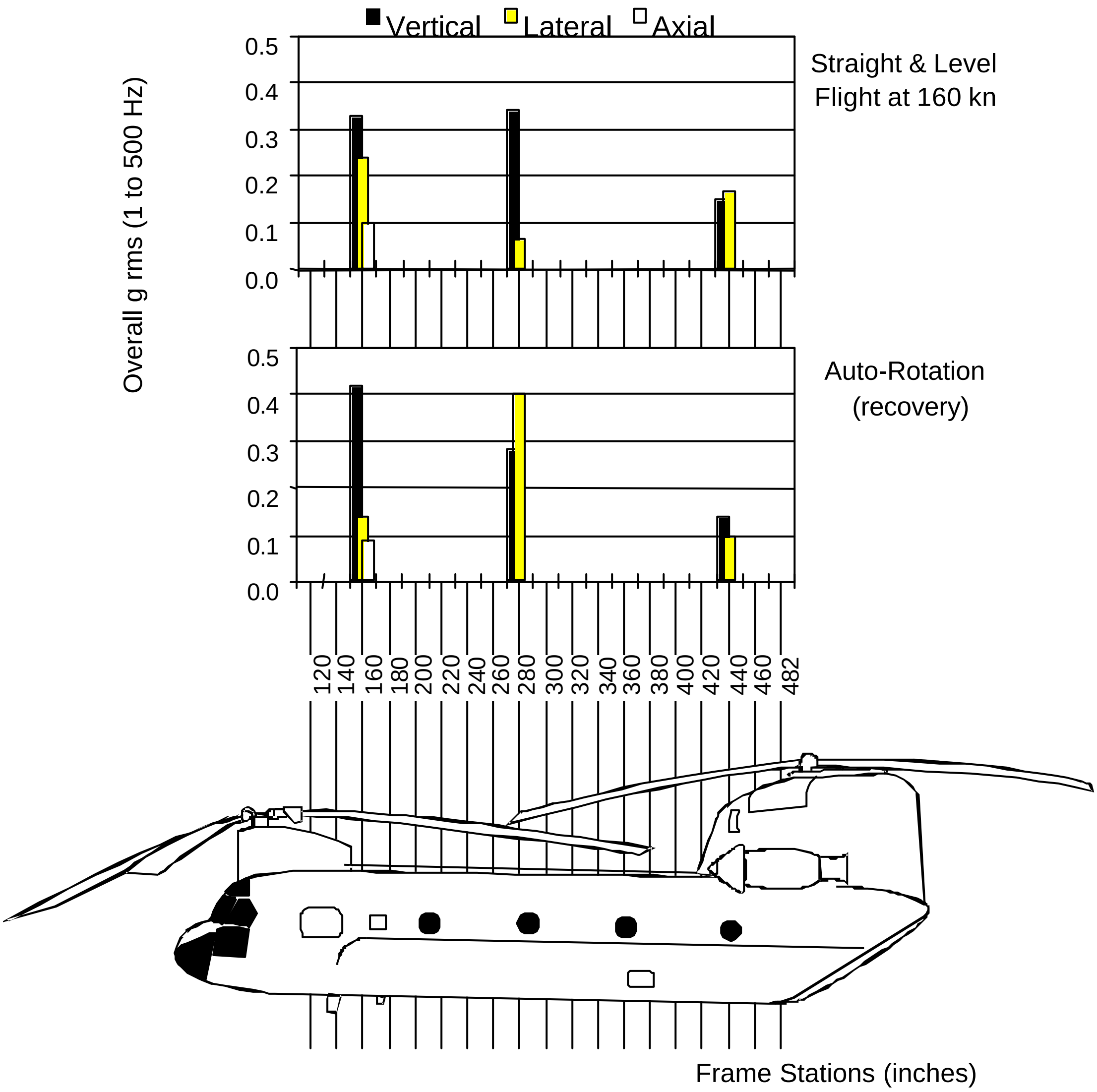


Figure 9 - Variation of vibration severity along the fuselage of a Chinook HC Mk1 helicopter

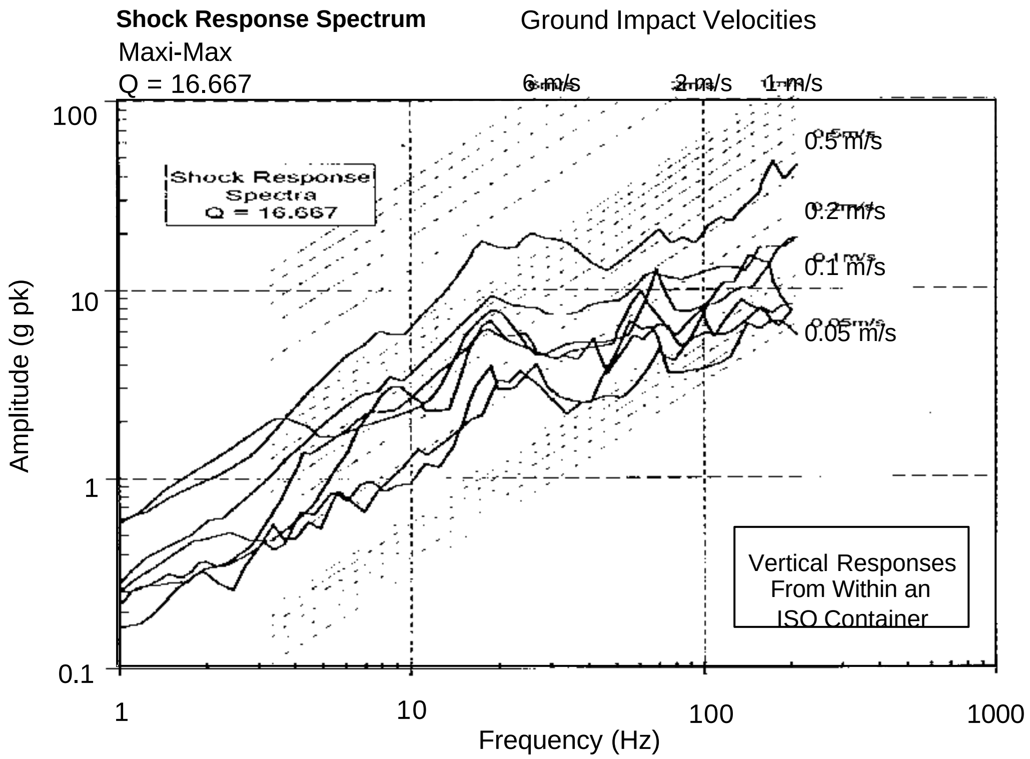


Figure 10 - Measured shock responses from the set-down of a load underslung from a Chinook HC Mk1 helicopter

SUB-SECTION 2/4 - SEA TRANSPORTATION UP TO FORWARD BASE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during sea transportation between places of manufacture and storage bases. The sources and characteristics of the mechanical environments are presented and information is also given on potential damaging effects.

1.2 The sub-section considers sea transportation by either naval or commercial vessels. For environmental conditions encountered when deployed on ships reference should be made to Section 8. In practice the normal operational mechanical environments encountered within warships are unlikely to be significantly different from those addressed here. However, for warships some critical design load cases are set, not by normal conditions, but by hostile cases. Such hostile cases are not addressed in this sub-section.

1.3 The dynamic excitations experienced by a payload during transportation by ship are mainly continuous vibratory motions. The continuous motions are principally vibrations arising from propulsion equipment and auxiliary machinery. In addition some responses occur due to sea motions. Accurate quantitative identification of the various sources of shipboard dynamic motions is often difficult due to the low levels involved. Any transient motions that do occur are usually associated with adverse sea states.

1.4 For the purpose of this sub-section materiel, which is the subject of the sea transportation environment, may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel. Unless specifically stated otherwise the environmental descriptions relate to the interface between the carriage vehicle and the payload. All axes relate to vessel axes, with the positive longitudinal axis of the right handed axis set coinciding with the direction of normal motion (ie: forward).

2. VIBRATION ENVIRONMENTS

2.1 Engine and Propulsion System

2.1.1 Vibration measurements made on payloads, carried in holds and on deck, usually indicate periodic motions related to engine speed and propeller blade passing frequency. The degree of contribution, from each of these components, appears to be related to proximity of the payload to the engine room or propulsion system. Responses from the holds of a UK Naval Armament Vessel (RMAS ARROCHAR) are shown in Figure 1. The responses illustrate the considerable number of essentially periodic components. These periodic components arise from auxiliary equipment in addition to the engine and propulsion system.

2.2 Auxiliary Equipment

2.2.1 The operation of auxiliary equipment gives rise to an apparent background random vibration, that essentially comprises a series of periodic motions arising from the auxiliary systems. The severity of these periodic motions is related to the proximity of specific auxiliary equipment. Air conditioning and generating equipment may give rise to significant amplitudes. However, measured data are not available for payloads in close proximity to such equipment.

2.3 Sea State Induced

2.3.1 However, the severity of payload vibratory motions seems to increase at higher sea states. Very little evidence exists to allow a relationship to be quantified, but a trend of increasing vibration severity with sea state can be identified in Figure 2. The information presented is from the same measurement source as for Figure 1. The severity of lateral responses seems to be influenced by the relative heading of the ship to the direction of the sea. Specifically the higher levels arise when the sea is transverse to the heading of the ship.

2.4 Potential Damaging Effects

2.4.1 For payloads with low natural frequencies, the periodic nature of the excitations arising from sea transportation coupled with the long duration of exposure may produce large cycle fatigue damage.

3. TRANSIENT ENVIRONMENTS

3.1 Green Sea Loading

3.2.1 Equipment carried as deck cargo may experience green sea frontal loadings of 70 kPa acting over 350 ms with transient loadings of 140 kPa for 15 ms.

3.2 Slamming

3.2.1 Higher sea states can give rise to transitory motions arising from waves impacting (or slamming) the ship's hull. The actual payload would not experience these excitations directly but rather the dynamic responses of the ships hull (natural frequencies are in the 2-5 Hz region) arising from these excitations. The severity and occurrence rate of such conditions, for the various categories of sea state, do not appear to be quantified. As the frequencies of these modes are very low compared to the flexible modes of all but a few payloads, the payload experiences mainly quasi-static loading rather than dynamic motions.

4. QUASI-STATIC ENVIRONMENTS

4.1 Quasi-Static Accelerations

4.1.1 During sea transportation steady state inertia accelerations are experienced. However, these are usually less than those experienced by most payloads during other phases of deployment.

4.2 Tilt

4.2.1 Payloads may be subject to static tilt of up to 30 degrees.

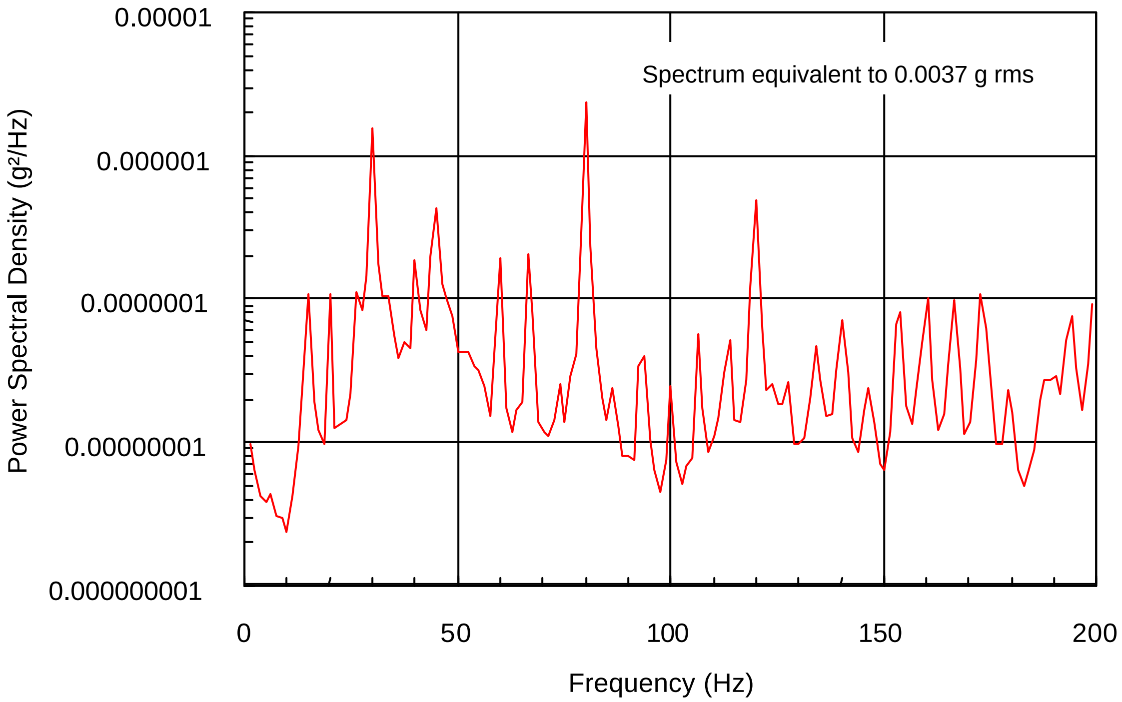


Figure 1 - Vibration spectrum from a transport ship's hold (vertical axis)

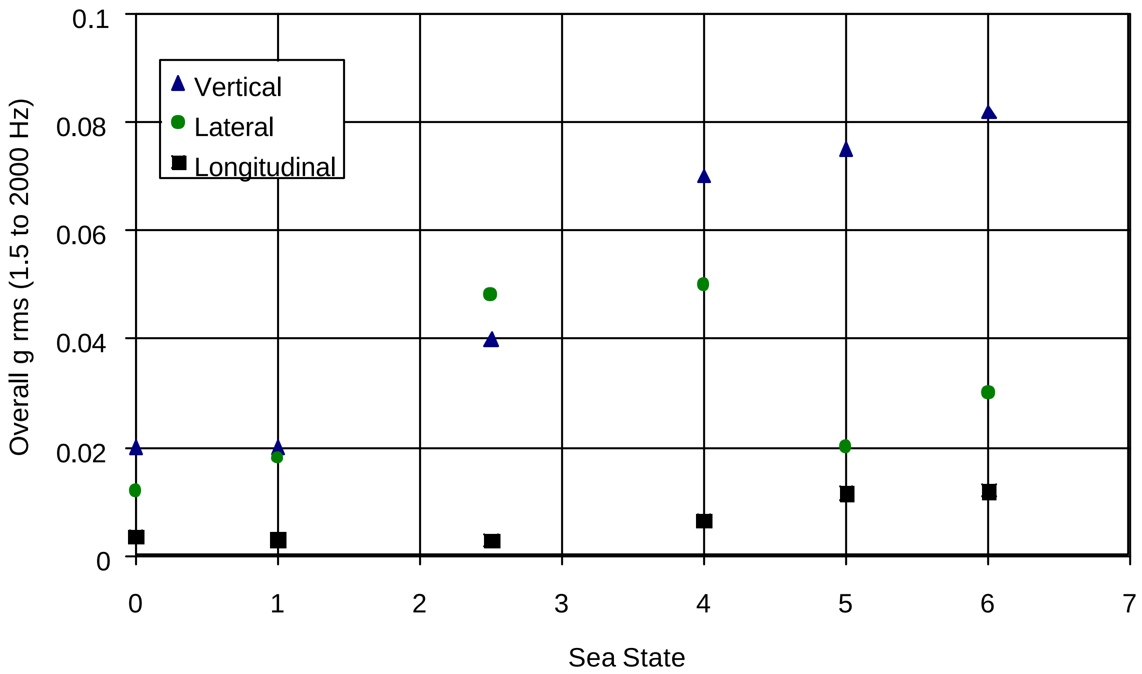


Figure 2 - Variation of vibration severity with sea state for a transport ship

SUB-SECTION 2/5 - TRANSPORTATION BEYOND FORWARD BASE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during transportation beyond the forward storage base. It specifically includes environmental conditions that may occur during carriage by wheeled vehicles on degraded and off road conditions. It also includes transportation by tracked vehicles such as Armoured Personnel Carriers (APCs).

1.2 This sub-section considers only transportation over land because the mechanical environment experienced by equipment when transported by air, sea and rail beyond the forward base are essentially identical to those up to the forward base. For specific information on the mechanical environments experienced by materiel occurring up to the forward base and related potential damaging effects reference should be made to Sub-sections 2/1, 2/2, 2/3 and 2/4 for road, rail, air and sea transportation respectively.

1.3 Procedural constraints during land transportation will be minimal beyond the forward base and therefore motions arising as a result of carriage as loose or unrestrained cargo are more likely.

1.4 For the purpose of this sub-section, materiel may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel.

1.5 Transportation beyond the forward base may utilise good quality made up roads, however, it must be assumed that transportation can equally occur over poor quality or damaged road surfaces, unmade tracks or even over cross country routes. All of these conditions are capable of producing dynamic responses more severe than those occurring during normal road transport. In addition certain types of vehicles may be utilised, such as tracked vehicles, which are not ordinarily used for normal carriage.

1.6 Payloads transported with limited restraint systems comprising straps, ropes, etc, are insufficient to prevent bounce and jostle occurring. For such payloads it is prudent to assume that the payload is both sufficiently well coupled to the vehicle to induce some vibration and shock responses and sufficiently uncoupled to allow bounce and jostle to occur.

2. WHEELED VEHICLES

2.1 A full description of the characteristics and excitation mechanisms causing dynamic responses when using normal roads is given in Sub-section 5/2.

2.2 Transportation over rough and degraded roads will change the relative contributions of the dynamic responses arising from the various mechanisms and sources, compared to those occurring during transportation on normal road surfaces. In particular, severely degraded road surfaces will result in much larger displacement motions at low (suspension) frequencies. In addition degraded road surface quality will produce higher severity transient responses. Figures 1 to 3 show the effects of carriage over rough road conditions (a rough concrete track at 24 km/hr - the highest speed the driver could be persuaded to traverse the track using a 4x4 10 tonne vehicle). These figures can be compared with figures in Sub-section 2/1 for normal road use (which originate from the same vehicle with the same driver and payload). The particular points to note are the increase in severity at low frequency and the perturbations in the probability density caused by the high amplitude/low occurrence rate transients.

2.3 Transportation over off-road and cross country conditions will accentuate the conditions referred to in the preceding paragraph. The number and amplitude of the transients will also increase, as will the severity of the low frequency responses. Vehicle speed is likely to decrease as a result of the extreme motion.

2.4 The use of trailers beyond the forward base will produce in most cases payload dynamic responses almost identical to those occurring on the vehicle itself. However, where trailers of lower mass, and with less sophisticated suspension systems are used, responses can become notably more severe than on the vehicle.

3. TRACKED VEHICLES

3.1 A full description of the characteristics and excitation mechanisms causing dynamic responses within tracked vehicles when using normal roads is given in Sub-section 5/1.

3.2 During transportation over rough and degraded roads the effects of the track plates on payload responses become less pronounced and the low frequency displacements and higher severity transient responses increase. These increases are greater than those on wheeled vehicles due to the less sophisticated suspension systems and greater speed capability of tracked vehicles on such surfaces.

3.3 During transportation over off-road and cross country routes the effects of track patter essentially disappear. However, both the low frequency displacements and transient responses increase. The latter can become very severe especially when the suspension system "bottoms out". The ability for a tracked vehicle to move at speed when using off-road and cross country routes accentuates these responses.

3.4 The observations regarding transportation by tracked trailers are essentially identical to those for wheeled vehicles stated in paragraph 2.4 above

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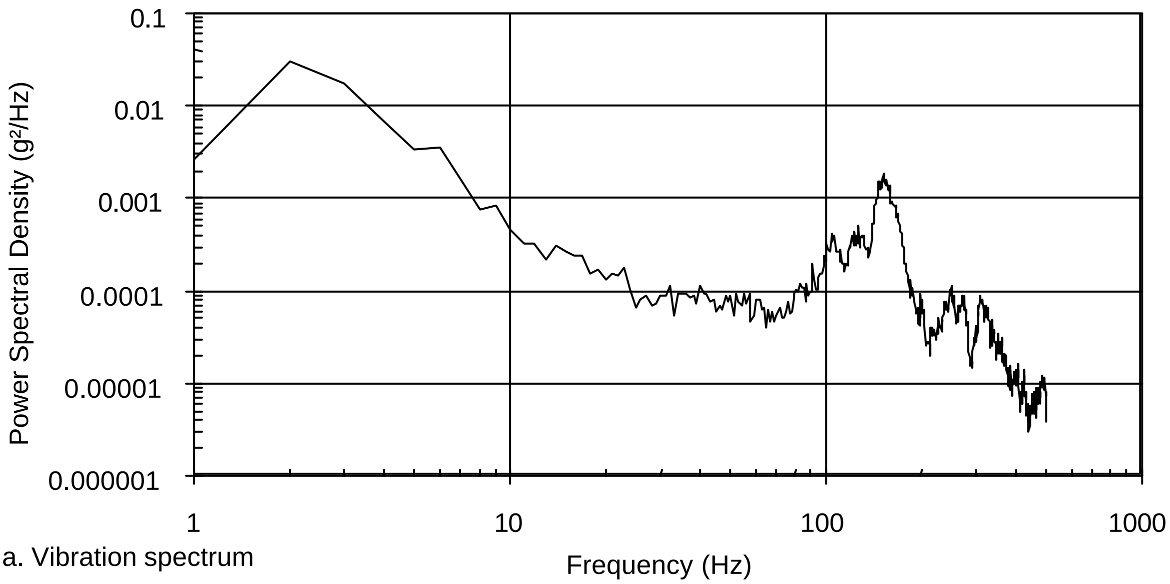
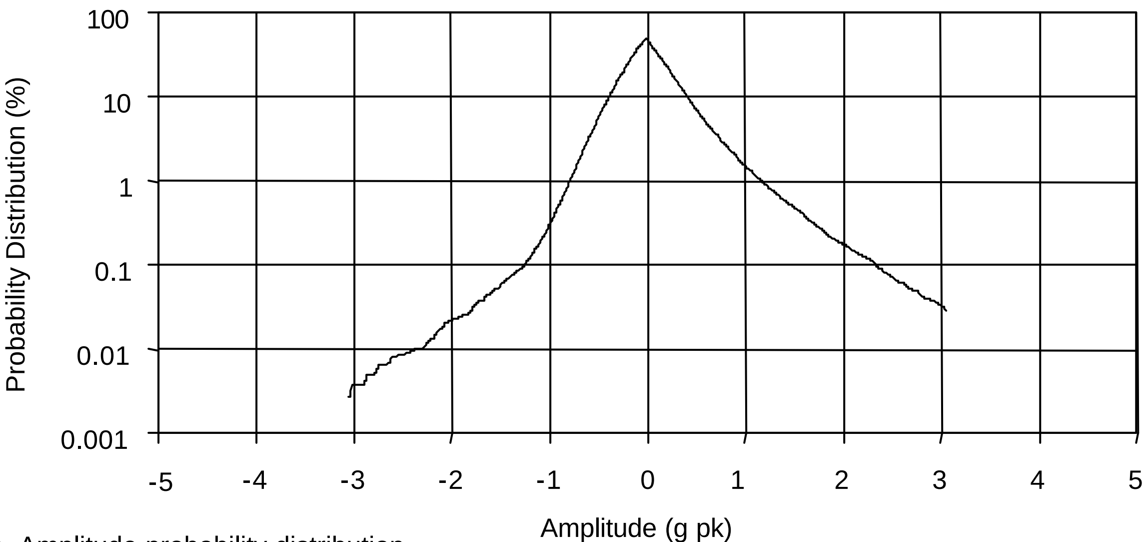
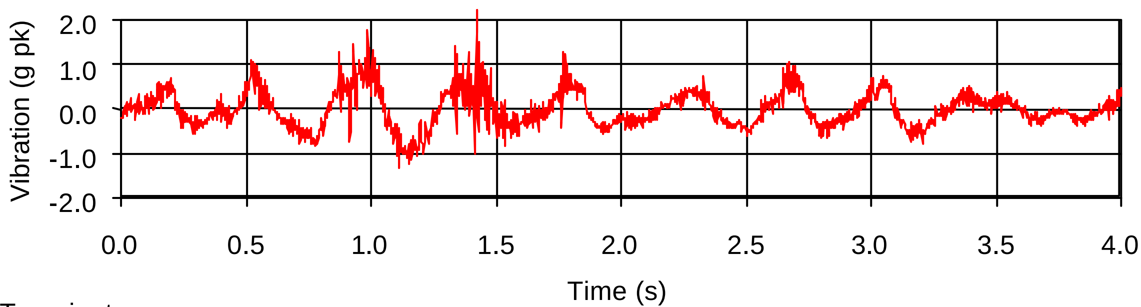


a. Vibration spectrum

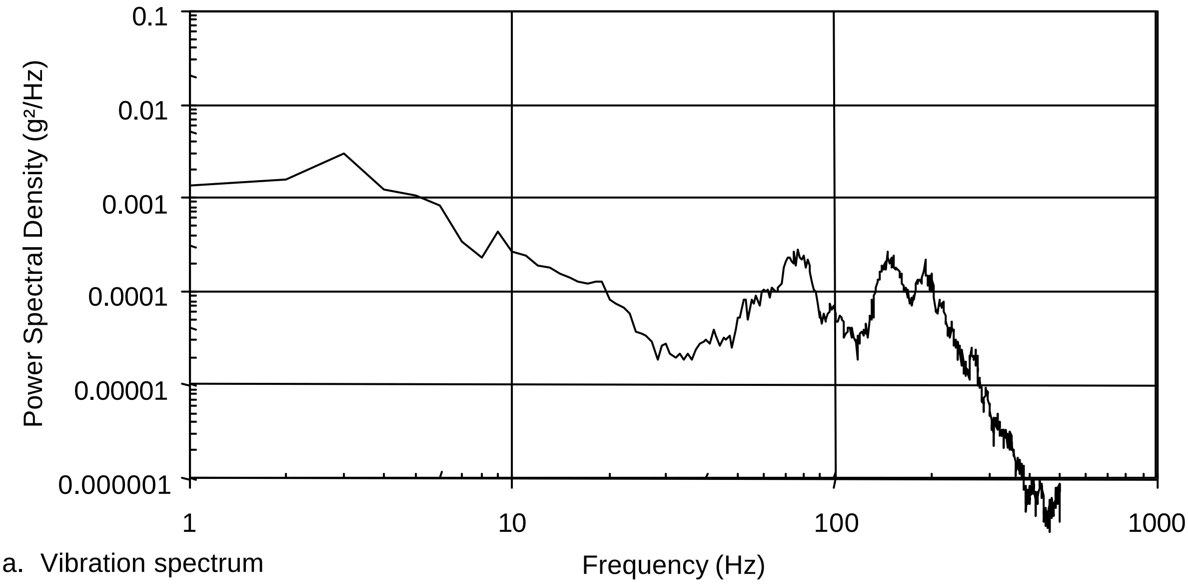


b. Amplitude probability distribution

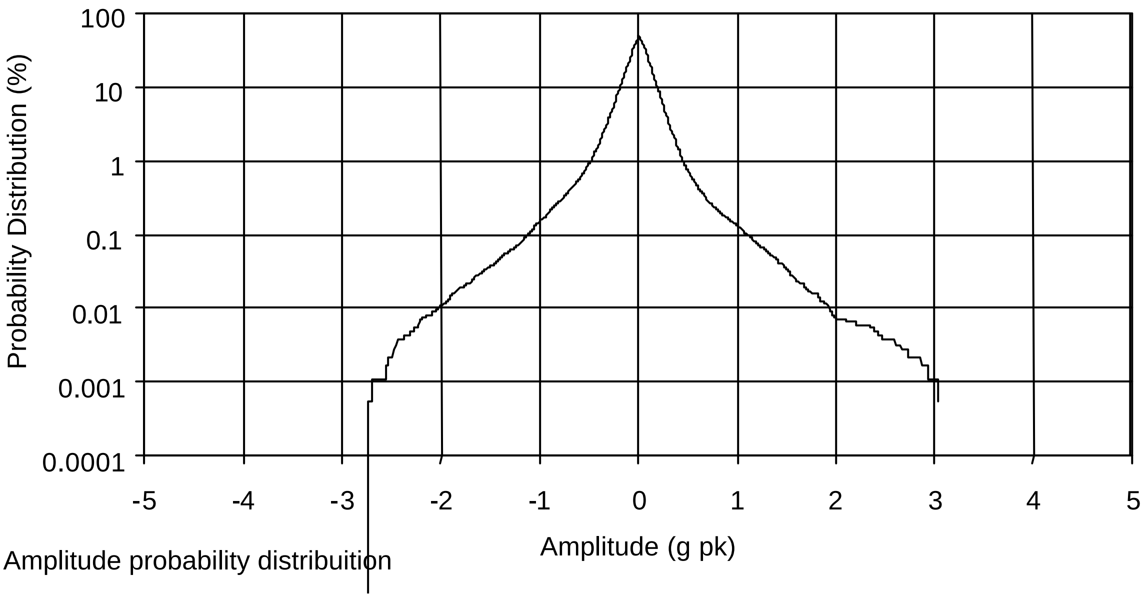


c. Transient response

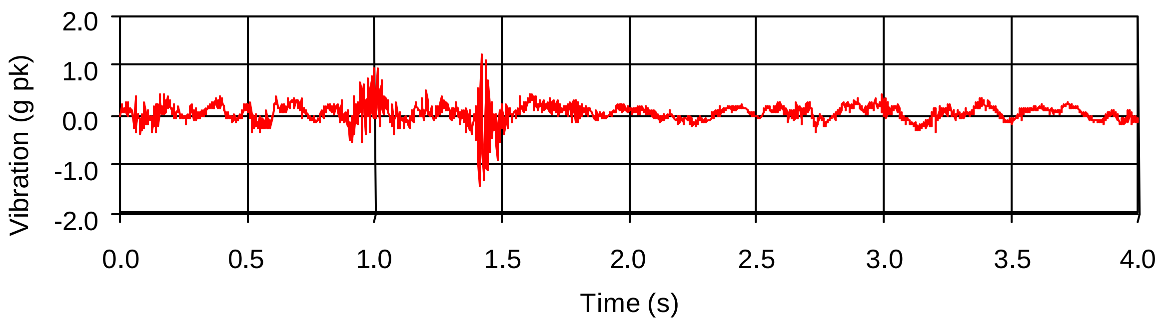
Figure 1 - Examples of vibration responses in the vertical axis measured during transportation on a rough road



a. Vibration spectrum

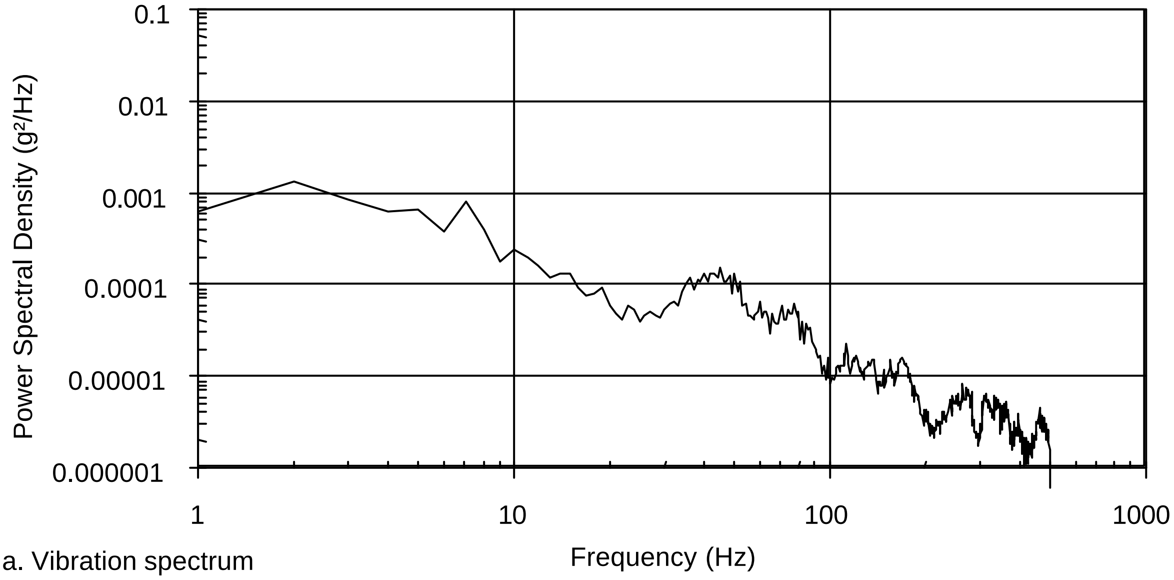


b. Amplitude probability distribuition

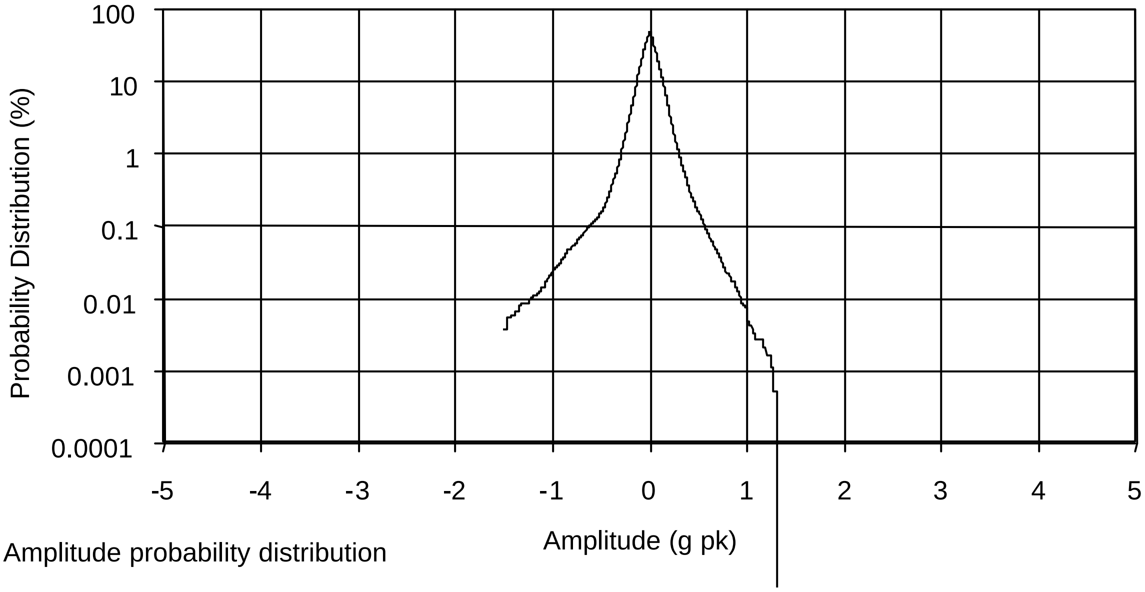


c. Transient response

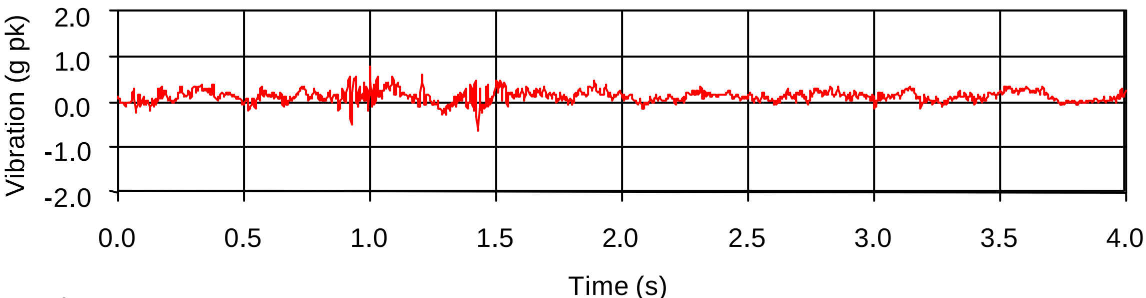
Figure 2 - Examples of vibration responses in the transverse axis measured during transportation on a rough road



a. Vibration spectrum



b. Amplitude probability distribution



c. Transient response

Figure 3 - Examples of vibration responses in the longitudinal axis measured during transportation on a rough road

SECTION 3

HANDLING AND STORAGE

SUB-SECTION 3/1 - HANDLING

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may occur during the handling of materiel. It includes the handling conditions associated with transportation and related logistical movements, and also those associated with deployment and operational use. During transportation materiel is usually packaged, whilst during deployment materiel is normally in its unpackaged state and as such may be relatively vulnerable.

1.2 For the purpose of this sub-section, materiel may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel.

1.3 Although for most materiel the mechanical environments experienced during handling are relatively benign, for sensitive equipments to be used in fixed installations these environments could be the most severe they are ever likely to experience.

1.4 The range of mechanical environments that may be experienced by materiel during handling is often constrained by specified procedures, or the use of special handling equipment or protective devices.

1.5 It is impractical to address the wide range of handling operations that could be applied to materiel. Therefore the following descriptive information relates only to the more commonly encountered modes of handling.

2. FORKLIFT VEHICLES

2.1 Several dynamic environments can arise from handling by forklift vehicles. These include lift up and set down shocks, and vibration during the vertical movement of the forklift platform. In general, these environments are benign. Of more significance are the transient dynamic motions that can be generated by a forklift vehicle when traversing irregular surfaces. Although procedures can specify the maximum speed of such vehicle operations, in practice it is difficult to enforce.

2.2 Whilst the type and size of the forklift vehicle, and the degree of loading, appear to have some influence on transient responses, their effects are not profoundly significant. Figure 1 shows envelope shock response spectra, in three axes, for four different (US) forklifts. Also, as most forklift vehicles have only small wheels and are equipped with only the simplest of suspension systems, the dynamic motions experienced by materiel during fork-lift vehicle operations are often not of gaussian form.

3. HOISTING AND LIFTING

3.1 During hoisting, acceleration and deceleration levels of around 2 g can be induced in materiel. In most cases these conditions can be treated as quasi-static loadings.

4. INTRA-FACILITY TRANSPORT

4.1 Transportation within a facility may utilise wheeled vehicles or trailers. Where such transportation is undertaken with restricted speeds and over good surfaces, the levels are benign. However, recent work identified that higher than expected levels can arise at commercial facilities such as airports. These higher levels arose because intra-facility transportation speeds were above those anticipated, but were generally below those that arise from road transportation.

4.2 It is likely that any packaging will be designed to protect materiel from shocks rather than vibration. Consequently significant amplification of the excitations may occur at low frequencies (10-50 Hz), which may give rise to materiel impacting with the inside of its packaging.

5. ROUGH HANDLING

5.1 The preparation of materiel for operational use, and in operational use itself, allows considerable potential for rough handling. At this stage materiel is often unprotected and is most vulnerable to such treatment. Potential incidences of rough handling should be identified through detailed examination of the relevant sections of the Manufacture to Target Sequence.

5.2 A severe condition usually adopted is to assume that materiel could be dropped from a bench or whilst being man carried (0.7 to 1 m). However, most materiel is unlikely to survive such a drop without serious consequences. Clearly only small items can be dropped in such a manner as it is usually difficult to subject large or heavy items to rough handling to this extent.

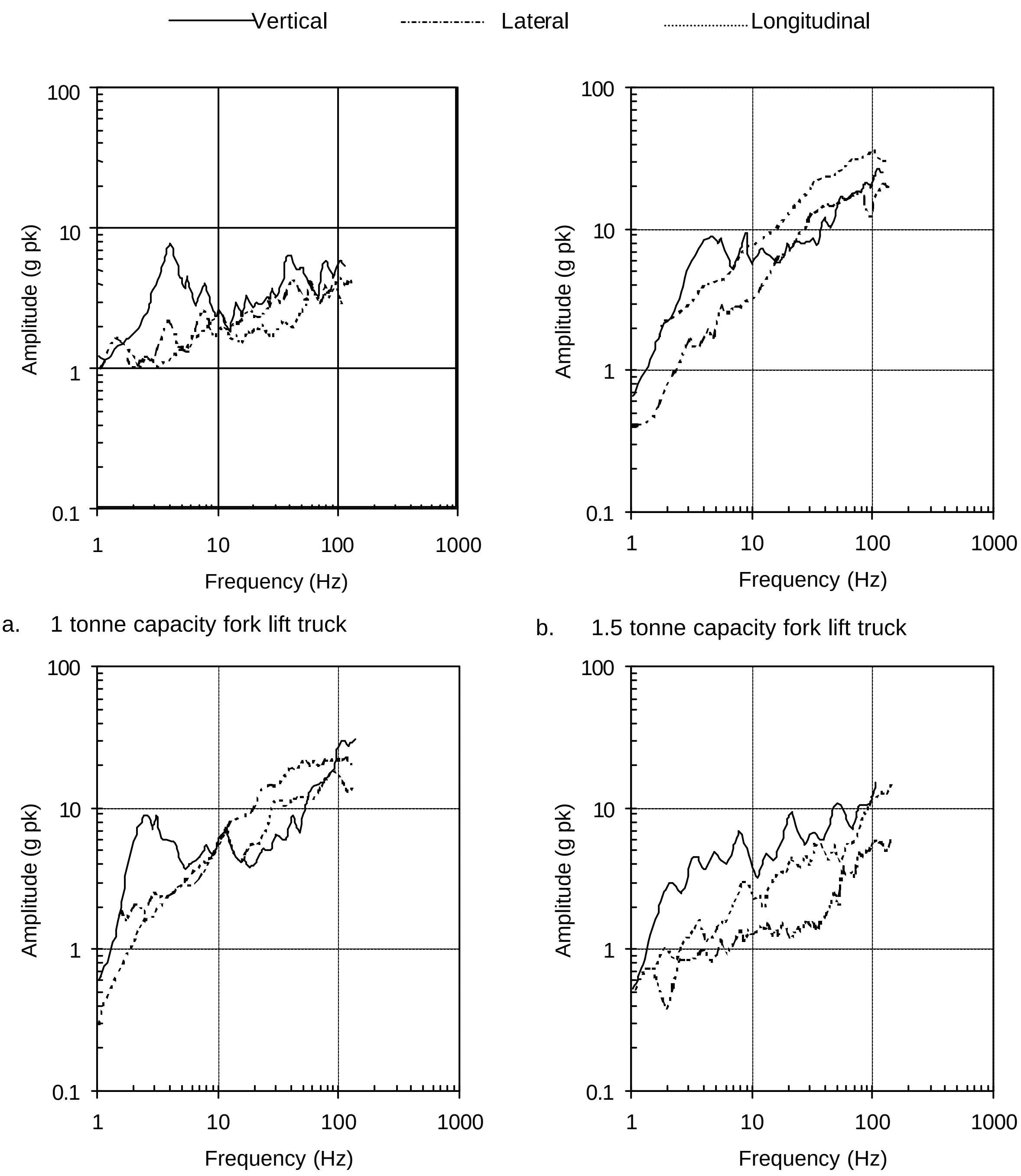
5.3 Rough handling may cause local structural damage and internal fractures. However if the packaging at the impact face, is relatively stiff then failure of internal equipment or structure may be induced as a result of acceleration loadings. During drop events significant displacements can arise which may cause materiel to impact with the inside of its packaging.

5.4 One method of establishing a rough handling severity is to determine the drop height that which will just produce visible external damage. The rationale is that visible external damage will necessitate a full materiel check before it is released for operational use.

6. SPECIAL PURPOSE HANDLING EQUIPMENT

6.1 Transient responses from a UK S-trolley, used to move stores around airfields, are shown in Figures 2 and 3. These figures show responses arising from traversing typical airfield obstacles such as landing lights at 8 and 16 km/h (5 and 10 mph) , and also the effects of snatch starts and emergency stops by the towing vehicle.

6.2 Trolleys, if improperly used, can induce severe vibration and shock conditions. The height constraint imposed on trolleys used to load torpedoes under helicopters allows only simple suspension systems to be employed. As a consequence, any rapid movement of these trolleys over deck discontinuities can result in severe induced shocks.



a. 1 tonne capacity fork lift truck

b. 1.5 tonne capacity fork lift truck

c. 2 tonne capacity fork lift truck

d. 3.5 tonne capacity fork lift truck

Note: All SRS computed using Q = 16.667

Figure 1 - Shock response spectra for transients measured on four fork lift trucks

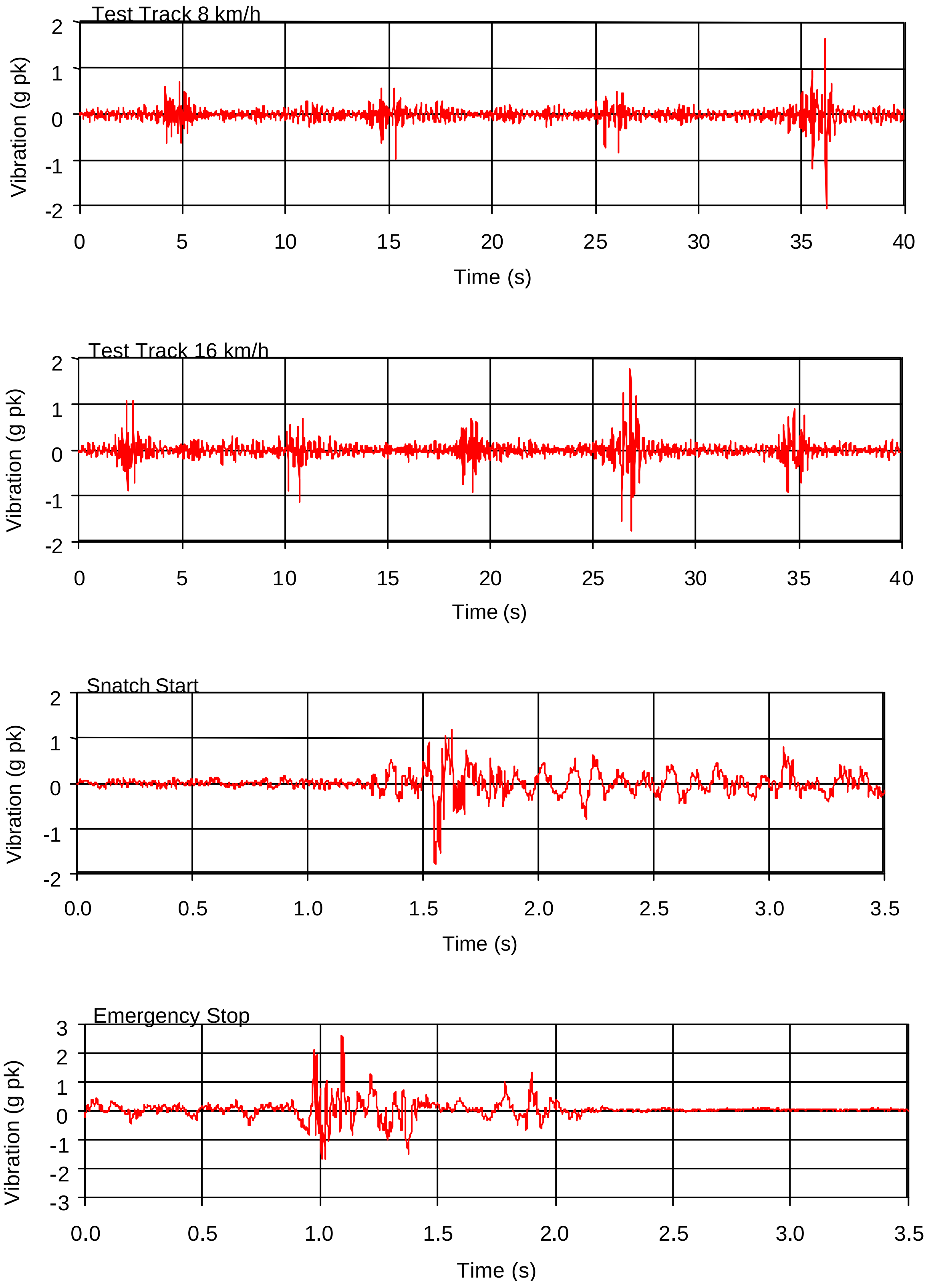


Figure 2 - Typical vertical responses from an airfield S-trolley

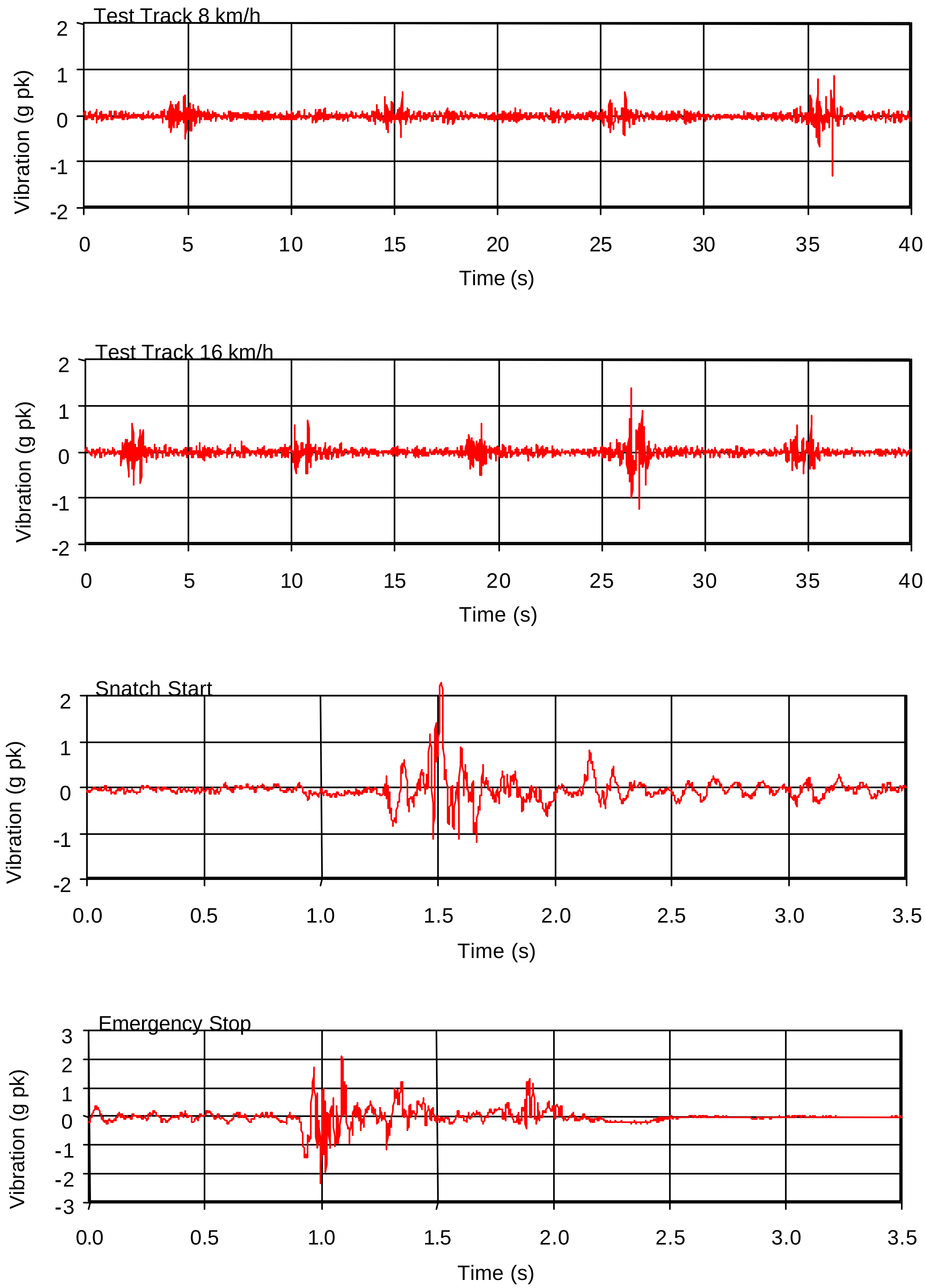


Figure 3 - Typical longitudinal responses from an airfield S-trolley

SUB-SECTION 3/2 - STORAGE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel during storage at a facility such as its place of manufacture, a base or depot, a shelter, a transit site, etc. It also encompasses storage conditions beyond such facilities, when environments normally associated with deployment may be experienced.

1.2 For the purpose of this sub-section, materiel may be unprotected or carried within some form of protection, package or container. A payload may consist of one or more items of materiel.

2. MECHANICAL LOADINGS

2.1 Mechanical loadings can be induced during storage as a result of:

a. the mass and stiffness distribution of materiel

b. the permitted stacking configurations for materiel

c. uneven floor and racking levels and associated support strengths on which materiel is stored.

These loadings can usually be treated using quasi-static analyses and test methods.

2.2 No dynamic mechanical environments are identified during storage. Dynamic environments arising from handling are the subject of Sub-Section 3/1.

2.3 Although ageing during storage can cause mechanical defects in materiel, such as permanent deformation in seals and drive belts, the ageing process is not in itself a mechanical induced environment.

2.4 The following are examples of problems that could occur when materiel and its container are subjected to the quasi-static mechanical loadings arising from the conditions described above:

a. failure or displacement of structural elements

b. loosening of screws, rivets, and fasteners

c. unacceptable deflection of cushioning elements

d. deterioration of climatic protection

e. damage to protective coatings

SECTION 4

MAN MOUNTED AND PORTABLE

SUB-SECTION 4/1 - MAN MOUNTED AND PORTABLE

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by man mounted and portable materiel. The conditions encompassed are those that may arise beyond the forward storage base. The sources and characteristics of the mechanical environments are presented and where appropriate, information is given on potential damaging effects.

1.2 The mechanical environments experienced by man portable materiel during tactical transportation include those that may arise from wheeled vehicles under both on-road and off-road conditions. They also encompass those that may occur in certain types of tracked vehicles such as Armoured Personnel Carriers (APCs). The mechanical environments considered also include tactical air transportation in fixed and rotary wing aircraft.

1.3 The majority of conditions experienced by man mounted materiel are identical, and indistinguishable, from those of man portable materiel. Therefore, only in very specific instances will the mechanical environmental conditions experienced by man mounted materiel vary from those of man portable materiel. Moreover, in these specific instances the environmental conditions (when man mounted) will be less severe than those occurring during other man handling conditions.

1.4 For the purposes of this sub-section materiel is considered to be unprotected by its normal transportation package or container. It may, however, be protected by secondary systems or “battlefield” protection devices.

2. TACTICAL GROUND TRANSPORTATION

2.1 The environmental conditions occurring during tactical transportation of man mounted and portable equipment are in many respects similar to those occurring during transportation beyond the forward base (addressed in Sub-section 2/5). However during tactical transportation, in addition to being essentially unprotected, the materiel is probably not securely restrained within the carriage vehicle. Any restraint that exists is unlikely to be sufficient to prevent bounce and jostle of the materiel occurring, and consequently, the resulting motions generate the major dynamic responses.

2.2 Whilst tactical transportation may utilise good quality made up roads, it must be assumed that transportation can also occur over poor quality or damaged road surfaces, unmade tracks and even over cross country routes. These inferior conditions are capable of producing significantly higher dynamic responses. Moreover, certain types of vehicles may be utilised which are not ordinarily used for normal transportation eg: APCs.

2.3 For unrestrained cargo the most damaging environmental conditions are those producing relatively large low frequency displacements and velocities. Increasingly rough surfaces and cross country conditions produce increasingly more severe dynamic responses. However, these conditions also reduce vehicle speeds and act to some extent to limit response amplitudes.

a. Wheeled Vehicles: The conditions causing dynamic responses in materiel during tactical carriage in wheeled vehicles are described in Sub-section 5/2. Although that sub-section deals with deployed materiel, the characteristics of the environments are very similar to those likely to be experienced by transported materiel.

b. Tracked Vehicles: The conditions causing the dynamic responses in materiel during tactical carriage in a tracked vehicle are described in Sub-section 5/1. Although that sub-section deals with deployed materiel the characteristics of the environments are very similar to those likely to be experienced by materiel during transportation.

3. TACTICAL AIR TRANSPORTATION

3.1 The characteristics of the environments arising from tactical transportation in fixed and rotary wing aircraft are unlikely to be sufficient to generate any significant bounce and jostle. As such the circumstances causing the mechanical environmental conditions will be essentially identical to those set out for normal air transportation in Sub-section 2/3.

4. MAN CARRIAGE

4.1 During man carriage, man portable materiel may be picked up, put down, dropped, moved or even thrown. The exact type and severity of environments arising from such handling will depend upon the size, mass and operational use of the materiel in question. In the majority of cases the most significant dynamic environments will arise from impact conditions. Such impacts can occur against a wide range of surfaces from soft mud to concrete. In addition the geometry of the surface may be flat or exhibit a high degree of irregularity.

4.2 In attempting to identify the limiting conditions it is useful to consider the wide range of possible impact scenarios. These scenarios should generate the worst case dynamic deceleration loads, penetration and bending likely to occur during battlefield handling conditions.

a. Impact: The materiel may be assumed to impact, at any conceivable angle, a hard rigid surface. The impact velocity is unlikely to exceed 3 m/s. This velocity should generate the limit deceleration conditions. Impacts against a hard surface may result in plastic deformations and distortions at the impact point. In addition the resultant deceleration loads may have the potential to produce loss of structural integrity or failure of internal equipment.

b. Spigot intrusion: The equipment may be assumed to impact, at any conceivable angle, a spigot. Again the impact velocity is unlikely to exceed 3 m/s. This velocity should generate the limit penetration conditions. The dimensions of the spigot will depend upon the operational scenarios. Impact against a spigot may result in penetration and an explosive event for munitions or a puncture leading to an explosion for pressure vessels.

c. Bending: Impact of the equipment over a trench, whose dimensions are such as to just prevent the equipment falling into it, will generate the limit dynamic bending conditions. Again the impact velocity is unlikely to exceed 3 m/s. In some cases the limit bending condition may be caused by the weight of a man acting at the centre of the equipment when deployed over a trench. High bending loads may produce loss of structural integrity and deformation sufficient to produce failure.

4.3 The previous paragraph indicates maximum potential impact velocities. However, these are considered to be upper limits for small, low mass equipments in tactical operational environments. For larger, heavier and bulky equipment these values may be reduced significantly.

5. MAN MOUNTED

5.1 The conditions experienced by man mounted materiel are in general similar to those for man portable materiel. Where differences do occur it is because the materiel is only deployed when attached to the man. In some circumstances man survival limits may drive the degree of equipment protection. However in most cases the necessary degree of robustness will be set to similar levels as for man portable materiel. Important exceptions may be aircrew helmet mounted materiel such as gun and night sights.

SECTION 5

DEPLOYMENT ON LAND VEHICLES

SUB-SECTION 5/1 - DEPLOYMENT ON TRACKED VEHICLES

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be encountered by materiel when deployed on or installed in tracked vehicles. The following categories of tracked vehicles are considered: main battle tanks, armoured fighting vehicles (including armoured personnel carriers), and logistics vehicles. The use of these vehicles in both on and off-road situations is addressed.

1.2 The sources and characteristics of the mechanical environments are presented and described, and where applicable, information is given on potentially damaging effects.

1.3 It is recognised that some critical design cases arise from the effects of hostile action such as blast or the use of explosive reactive armour. Such hostile environments are not addressed in this sub-section.

1.4 When a tracked vehicle moves across a terrain, interactions between the vehicle's tracks and irregularities in the terrain result in vibration excitation being transmitted to the vehicle's installed materiel via the suspension system and hull structure. Vibration is also generated by the action of the tracks moving over their wheels, sprockets and rollers (Figure 1 refers) which can pass directly into the vehicle's hull. In addition, materiel will experience inertial loadings arising from the vehicle's acceleration, eg: when increasing speed, braking, cornering, etc.

1.5 The action of the vehicle's engine, transmission, pumps, etc, can also give rise to vibration, which is likely to be most significant at discrete frequencies associated with rotating shafts, gear meshing, etc. The significance of these excitations is strongly dependent on the position of the materiel relative to these sources.

1.6 Vibration spectra acquired from the measurements on tracked vehicles comprise a wide band random spectrum upon which is superimposed a number of relatively low frequency narrow band peaks. An example of such a spectrum is shown in Figure 2. The impact of successive track plates on the ground is perceived within the vehicle as narrow band spectral components, which can be severe. These narrow band components are speed dependent and relate to the fundamental track patter frequency and usually several higher harmonics. The wide band component is generated by the combined effects of the rolling of the wheels on the tracks, interactions between the track links and the various other sources including engine, gearbox, generators, etc. Peaks in response frequencies corresponding to the vehicle's suspension system can be expected to be low, eg: <3 Hz. Relatively broad band peaks in frequencies may also be evident corresponding to structural dynamic modes of the vehicle itself. These modes may lie in the 20 to 100 Hz frequency range.

1.7 The dynamic response of materiel deployed on a tracked vehicle depends on terrain type, vehicle characteristics and vehicle operation. These three aspects are discussed below.

2. TERRAIN TYPE

2.1 The nature of terrain experienced by a tracked vehicle will significantly influence the response of the materiel. Terrains which may need to be considered depend upon the role of the vehicle, and could include classified roads, rough roads, pavé, etc, in addition to cross-country. As noted above, the action of the track plates impacting on the ground may be a major source of vibration. Therefore hard surfaces, including classified roads, are likely to provide a more severe environment than softer terrains such as cross country, which tend to cushion the impact of track links on contact with the ground. This is in contrast to the trend associated with wheeled vehicles, which produce relatively benign vibration loadings on classified roads. An example for a tracked vehicle of how vibration responses, expressed as overall g rms, vary with respect to terrain type, is shown in Figure 3.

3. VEHICLE CHARACTERISTICS

3.1 The vibration environment associated with main battle tanks is particularly severe. The contributing factors are the stiffness of their suspension systems, their overall structural rigidity and lack of damping, their powerful engines and track systems.

3.2 Other tracked armoured fighting vehicles (AFVs) tend to produce a similar dynamic environment to that of main battle tanks but the severity is dependent upon vehicle design.

3.3 Logistics vehicles are not armoured and are often based on standard chassis designs. The vibration severity of these vehicles is likely to reflect the design aims of their chassis, which may be to meet either commercial or military requirements. The vibration environment for logistics vehicles built on military chassis would be expected to be more severe than those built on commercial chassis because of their relatively high suspension system stiffness and structural rigidity.

3.4 The type of track plates fitted to a tracked vehicle is a major influence on the vibration environment within the vehicle. Two aspects of plate design can influence vibration severity.

a. Plate Connections: There are a number of different designs used to connect the plates together. Recent work has shown that for AFVs, hull vibration in terms of the overall g rms (0 to 1000 Hz) associated with a dry pin design of track is up to 2 times as severe as that associated with end connector track. See illustration at Figures 4 and 5.

b. Plate Facings: The type of facing fitted to the metal track plates should reflect the type of terrain that a vehicle may be expected to encounter. For example, rubber facings are often used when a vehicle is to spend a high proportion of its time on classified roads. Whilst these are fitted to avoid damage to the road surface by the track, a secondary effect is to reduce significantly the severity of track patter vibration.

3.5 The agility of a vehicle is related to its power to weight ratio. Modern AFVs tend to have high power to weight ratios and are therefore capable of high speeds, eg: greater than 60 km/hr. As vibration severity tends to increase with speed, there is reason to expect that high power to weight ratio vehicles will produce an increase in the severity of the dynamic environments. Higher speeds will also extend the frequencies of the track patter harmonics.

4. VEHICULE OPERATION

4.1 In general, vehicle structural vibration severity can be expected to increase as vehicle speed increases but g rms levels do not increase linearly with speed.

4.2 If resonances are excited, the maximum vibration responses of installed materiel do not necessarily occur at the vehicle's maximum speed. Such resonances could be associated with the vehicle's structure, the particular item of materiel or its mounting arrangements.

4.3 Recent work indicates that for AFVs, vibration during cornering is considerably more severe than when travelling in a straight line, eg: by up to 2 times for the hull and up to 2.5 times in the turret in terms of the overall g rms (0 to 1000 Hz).

4.4 As tracked vehicle operations can induce high levels of vibration in installed materiel, for items that are not securely fastened, problems can arise through the actions of scuffing, fretting and brinelling. These kinds of surface degradation could provide problems for optical instruments such as sighting equipment. Another area of concern is of possible coupling between vehicle excitation at track patter frequencies and the response of equipment, ie: associated with the equipment itself or its mounting arrangement. As the fundamental track patter frequency varies, according to vehicle speed, between 0 and perhaps 150 Hz depending on vehicle type, it can be difficult to avoid such coincidences at all times. This problem is exacerbated when strong harmonics of track patter are evident.

4.5 Steady-state accelerations will be experienced by the vehicle when increasing speed, braking or cornering. Such levels are unlikely to exceed 1 g during use on classified roads. During off-road use, accelerations arising from jolts as uneven terrains are traversed may exceed 1 g.

4.6 Some materiel might be susceptible to vehicle tilt, which may become significant in off-road conditions. In such circumstances, tilt angles beyond 45 degrees may be encountered.

5. MATERIEL POSITION AND MOUNTING

5.1 The severity of the environment perceived by a munition installed in a vehicle depends on where the materiel is mounted. Evidence suggests that hull vibration, expressed as the overall g rms (0 to 1000 Hz), can be between 1.3 and 5.7 times more severe than in the turret, depending on vehicle type and measurement axis. With respect to the relative severity of axes, vibration in the vertical axis in the hull or turret has been seen to be around 1.5 times more severe that in the transverse or longitudinal axes. The mass and mounting arrangements of the materiel can also influence its response.

6. GUNFIRE AND LAUNCH OF WEAPONS

6.1 The launch of weapons and the firing of guns can subject the vehicle to high levels of shock, vibration and blast pressure. These conditions are highly specific to particular installations and therefore generalised guidance on their characteristics is inappropriate.

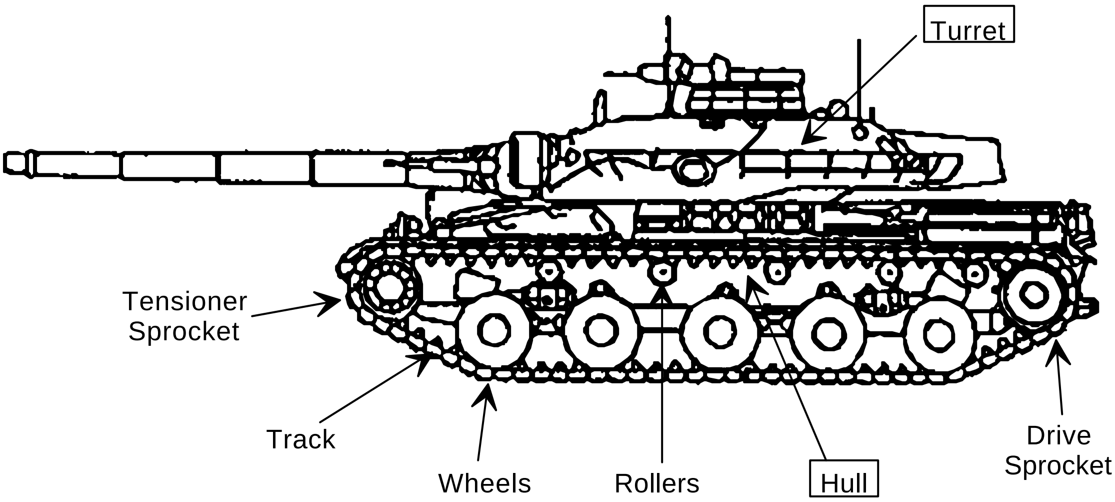


Figure 1 - Materiel mounting zones and track features for a main battle tank

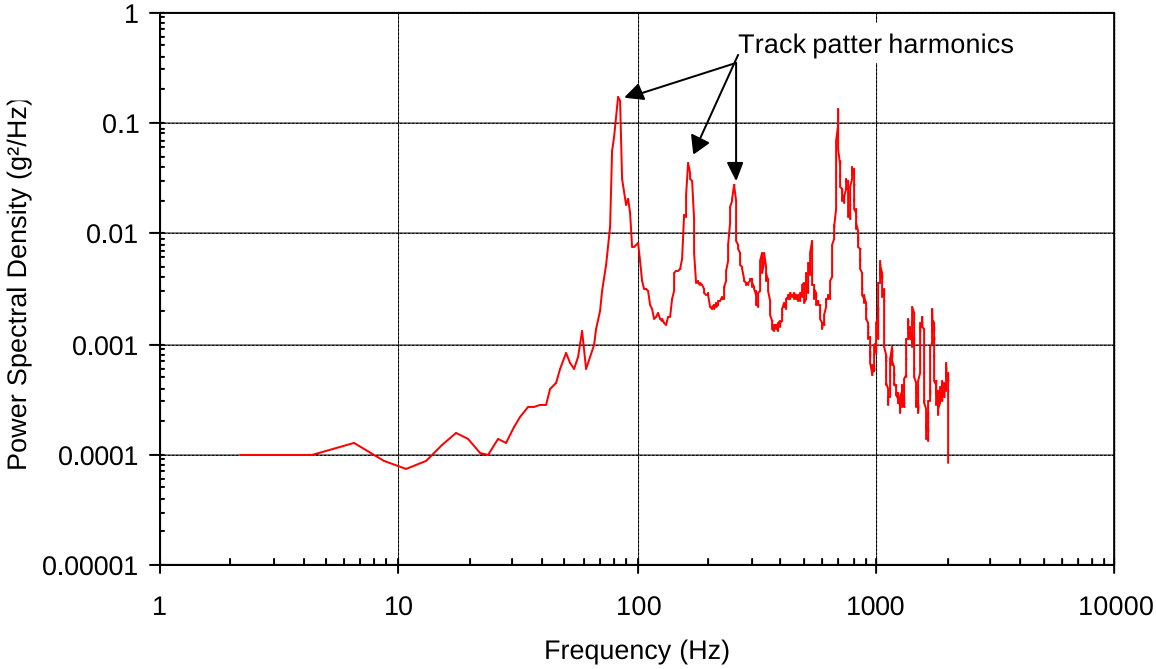


Figure 2 - Vibration spectrum for a tracked vehicle

Notes:

1. *Data from the hull of an armoured fighting vehicle running on a Tarmacadam surface at 50 kph*
2. *Spectrum is equivalent to 3.25 g rms (vertical axis)*

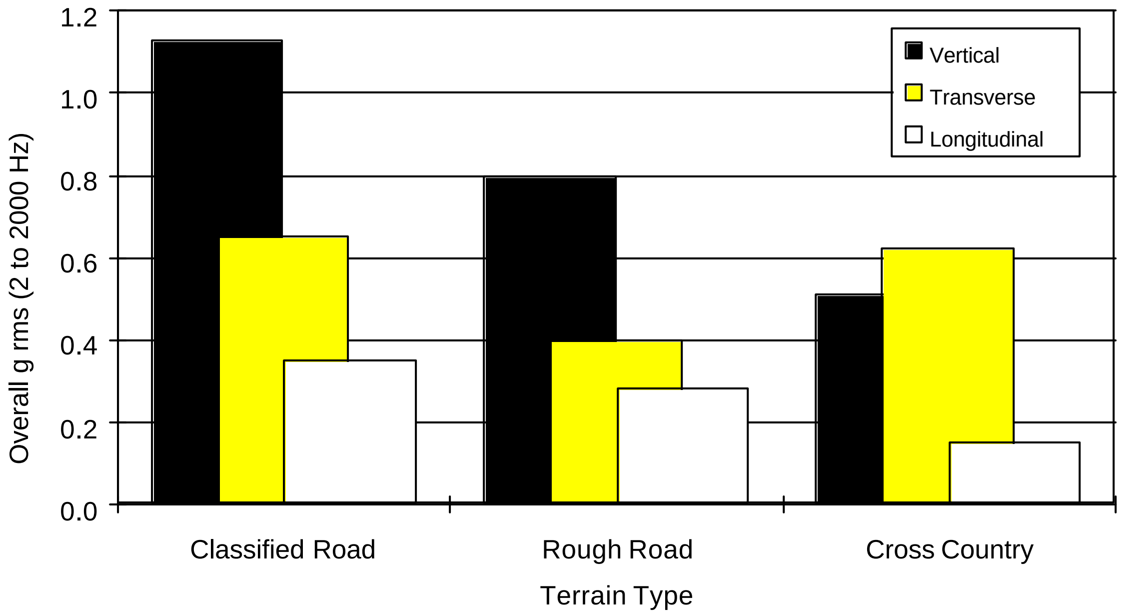
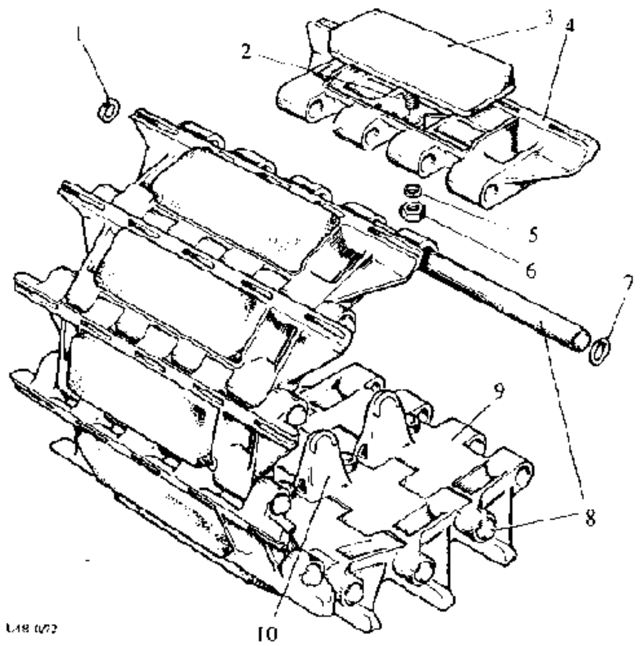


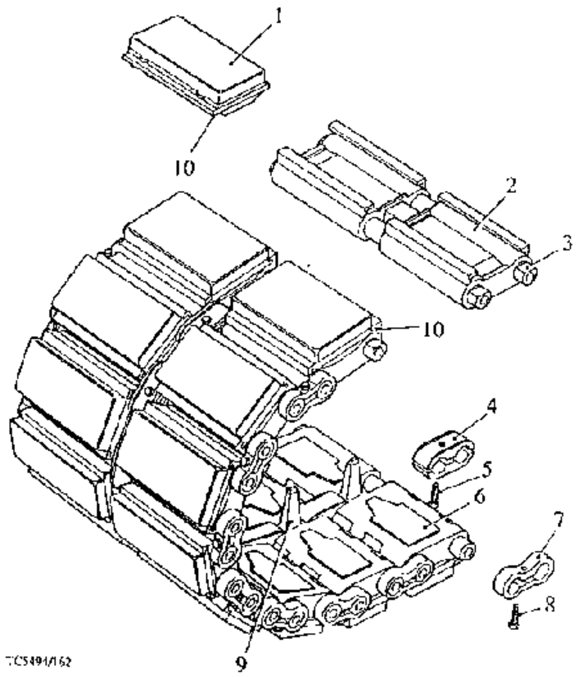
Figure 3 - Relative severity of terrains for a tracked vehicle



Key

1. Circlip
2. Retaining bolt
3. Rubber pad
4. Link grouser
5. Lock washer
6. Nut
7. Circlip
8. Track pin
9. Track pin lugs
10. Horn

Figure 4 - Dry pin track type



Key

1. Track pad
2. Track link
3. Track pin
4. Centre connector
5. Screw
6. Rubber insert moulding
7. End Connector
8. Screw
9. Horn
10. Projection

Figure 5 - End connector track type

SUB-SECTION 5/2 - DEPLOYMENT ON WHEELED VEHICLES

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be encountered by materiel when deployed on or installed in wheeled vehicles.

1.2 The vehicles considered in this sub-section range from large conventional trucks to small four wheel drive types, and may be armoured or unarmoured. Trailers are also considered and may be of two or four wheeled types, ranging in size from those towed behind a small four wheel drive vehicle to those towed behind the largest logistic vehicles. Many different types of trailers are in general use, some of which may be custom built for specific applications.

1.3 The application modes considered are the “Common Carrier” mode which covers vehicle use on predominantly classified roads and includes commercial transportation, and the “Mission/Field” mode which covers vehicle use in predominantly off-road situations.

1.4 The sources and characteristics of the environments are presented and described, and when applicable information is given on potential damaging effects.

1.5 When a wheeled vehicle moves across a terrain, interactions between the vehicle’s tyres and irregularities in the terrain result in vibration excitation being transmitted to the vehicle’s installed materiel via the suspension system and chassis structure. In addition, materiel will experience inertial loadings arising from the vehicle's acceleration, eg: when increasing speed, braking and cornering.

1.6 The action of the vehicle’s engine, transmission, pumps, etc, can also give rise to vibration excitation. Such excitation is likely to be most significant at discrete frequencies associated with rotating shafts, gear meshing, etc. Tyre resonances can also be a source of excitation. The significance of these excitations is strongly dependent on the position of the materiel relative to these sources.

1.7 Vibration spectra acquired from measurements on wheeled vehicles and trailers are essentially wide band random. Peaks in the spectra can be expected to be associated with the vehicle's mass and the compliance of its suspension system. Discrete peaks may be evident in such spectra at frequencies associated with the various rotating components, eg: associated with the engine and transmission.

1.8 Considering structurally transmitted shock, only moderate severities are expected in the Common Carrier role, which involves medium mobility vehicles that spend a high proportion of their life on normal paved roads. Conversely, higher shock levels can be expected in the Mission/Field role, which involves high mobility vehicles that may operate in an off-road role, possibly in combat.

1.9 The dynamic response of materiel deployed on a wheeled vehicle depends on terrain type, vehicle characteristics and vehicle operation. These three aspects are discussed below.

2. TERRAIN TYPE

2.1 The nature of terrain experienced by a wheeled vehicle will significantly influence the response of the materiel. Terrains which may need to be considered depend upon the role of the vehicle and could include classified paved roads, rough roads, Belgium Block (pavé), cross-country, etc. As may be expected, hard and rough terrains, such as broken concrete tracks, give rise to a more severe environment than classified roads, as illustrated in Figure 1. Further examples of how vibration responses, expressed as overall g rms, vary with respect to terrain type, are shown in Figure 2.

2.2 Even for a classified road with a nominally good surface, a whole range of surface irregularities such as pot-holes and railway tracks may be encountered in normal use. Consequently, the distinction between vibration and shock is often obscure in measured dynamic responses from wheeled vehicles. Evidence of this can often be seen in measured amplitude probability distributions, see Figure 3a. This figure shows a characteristic of a smooth, continuous curve from the region of high probability low amplitude to regions of lower probability higher amplitudes. It is further noted from Figure 3b that the flared character of the corresponding probability density plot indicates that this data is not from a simple, stationary gaussian process, which would result in a triangular characteristic.

2.3 Regarding the effects of classified roads on vibration, severities are likely to be indicative of minimum road width rather than surface quality. Whilst recent work has indicated that, for a given speed, least vibration is usually associated with “multiple” track roads and worst vibration with “contra-flow” roads, the reason in that the reduced width of a “contra-flow” track road will increase the likelihood of encountering shock transients, caused by running over a recessed gutter, drain cover or mounting a kerb.

2.4 On rough roads and pavé when shocks might be expected, the dynamic environment can be so severe for so much of the time that it is usual to describe this environment as a continuous vibration condition. In these cases, both the rms and peak response amplitudes can be high.

2.5 On cross country tracks, the general level of severity can be low but severe shocks can occur. Consequently, rms amplitudes can be low but peak amplitudes relatively high.

3. VEHICLE CHARACTERISTICS

3.1 The vibration perceived by materiel will be significantly influenced by the vehicle’s suspension system and tyres. A vehicle with a soft suspension system with plenty of available travel, fitted with soft tyres, can be expected to produce a benign environment. Conversely, vehicles with stiff suspension systems and hard tyres, eg: armoured vehicles, can be expected to produce a relatively harsh environment, particularly when negotiating rough hard surfaces such as broken concrete or desert shale. Severe shocks can occur if all the available suspension travel is expended and the bump stops are used.

3.2 The laden weight of a particular vehicle can also be expected to influence vibration severity. Evidence indicates that the vibration severity decreases as the vehicle load increases, as illustrated in Figure 4.

3.3 The position of materiel in a vehicle or trailer can influence its dynamic response. For example, Figure 5 shows the pattern of vibration severity along the length of an articulated, multi-axle semi-trailer. The mass and mounting arrangements or the materiel can also influence its dynamic response, particularly if anti-shock mounts are used.

3.4 Vibration perceived by materiel is the vector sum of excitation transmitted from each wheel, together with any other sources associated with the engine or transmissions etc. It has been suggested that the excitation at each wheel from the road surface is not independent but may be highly correlated. These effects are unlikely to be significant for small installations, such as those with a small base area, but may need to be taken into account when compiling test severities from measured data for large installations, particularly in respect of the vehicle's rotational motions.

3.5 For trailers the severity of the dynamic environment is likely to be most severe for a small two wheeled type. As the size of trailers increase, the environment tends to that of a wheeled vehicle of similar load carrying capacity. As a general rule, if a trailer's laden weight exceeds 2 tonnes it is likely to behave as an equivalent wheeled vehicle. Lost motion in a vehicle/trailer coupling can give rise to significant shocks both to the towing vehicle and trailer. In practice, all but the smallest trailers would be expected to benefit from couplings incorporating longitudinal dampers.

4. VEHICLE OPERATION

4.1 The severity of a vehicle's structural dynamic response, described by the overall rms amplitude, can be expected to increase as vehicle speed increases, as illustrated in Figure 6. If resonances are excited, the maximum vibration of particular installed materiel does not necessarily occur at the vehicle's maximum speed, as shown in Figure 7. Such resonances could be associated with the particular item of materiel or its mounting arrangements.

4.2 Recent work on a heavy truck (>35 tonnes) indicates that, on good quality roads, g pk responses during snatch starts and emergency stops are likely to be encompassed by those associated with normal road running. In addition, as may be expected, relatively high levels can be experienced during these events in the vehicle's longitudinal axis when compared to normal road running. In general steady-state accelerations experienced by the vehicle are unlikely to exceed 1 g. Vibration during acceleration, braking and cornering is unlikely to be very different from that during equivalent steady speed conditions.

4.3 Any wheeled vehicle running with one or more deflated tyres can be expected to experience a worse dynamic environment than under normal circumstances with all tyres properly inflated. In terms of spectral characteristics, the effects of deflated tyres may be limited to only a part of the spectrum, as illustrated in Figure 8.

4.4 Vehicle tilt may be especially significant for sensitive materiel in off-road vehicles in the Mission/Field role.

4.5 Materiel that is installed using anti-shock mounts could experience relatively large displacements if the natural frequency of the materiel on its mounts coincided with vehicle suspension frequencies.

4.6 Should any resonant frequencies of the materiel correspond to any of the rotational sources of vehicle vibration such as drive shaft speed, excessive vibration could result. These effects could be significant during convoy operations.

5. GUNFIRE AND LAUNCH OF WEAPONS

5.1 The launch of weapons can subject the vehicle to high levels of shock, vibration and blast pressure. These conditions are highly specific to particular installations and therefore there characteristics are not addressed in this sub-section.

5.2 As sensitive materiel is likely to be mounted within the vehicle, the effects of blast pressure waves associated with gunfire are unlikely to be significant. However, possible adverse effects could arise from a coupling of gun firing rate with vehicle structural frequencies or with the installed frequencies of equipment.

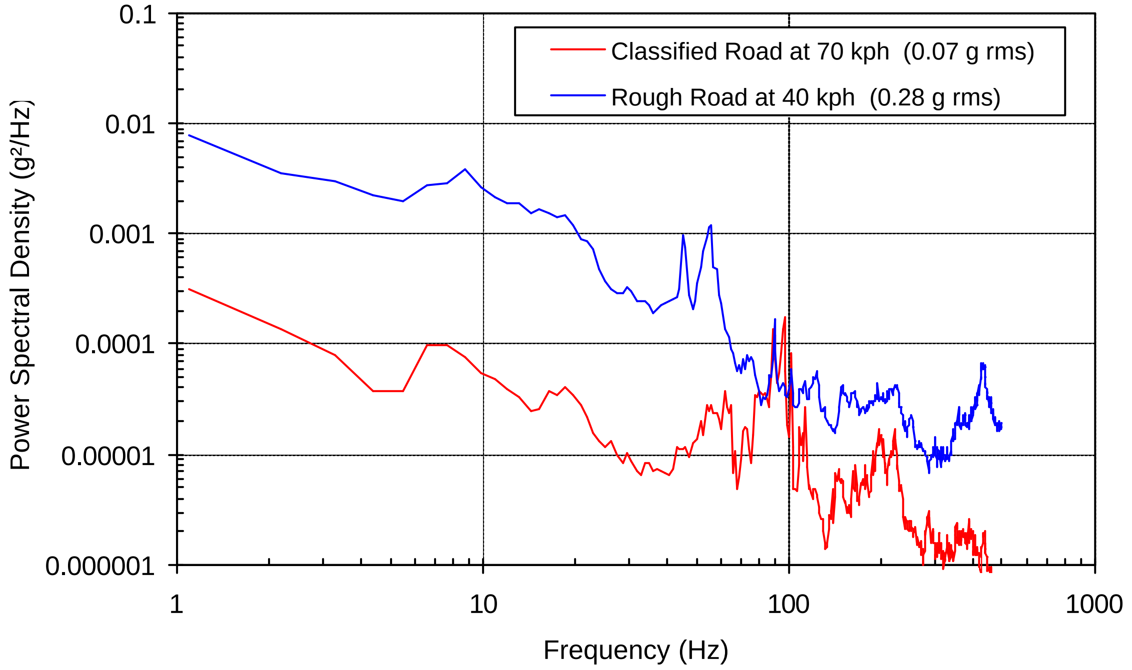


Figure 1 - Vibration spectra for rough and classified roads - small four wheel drive vehicle

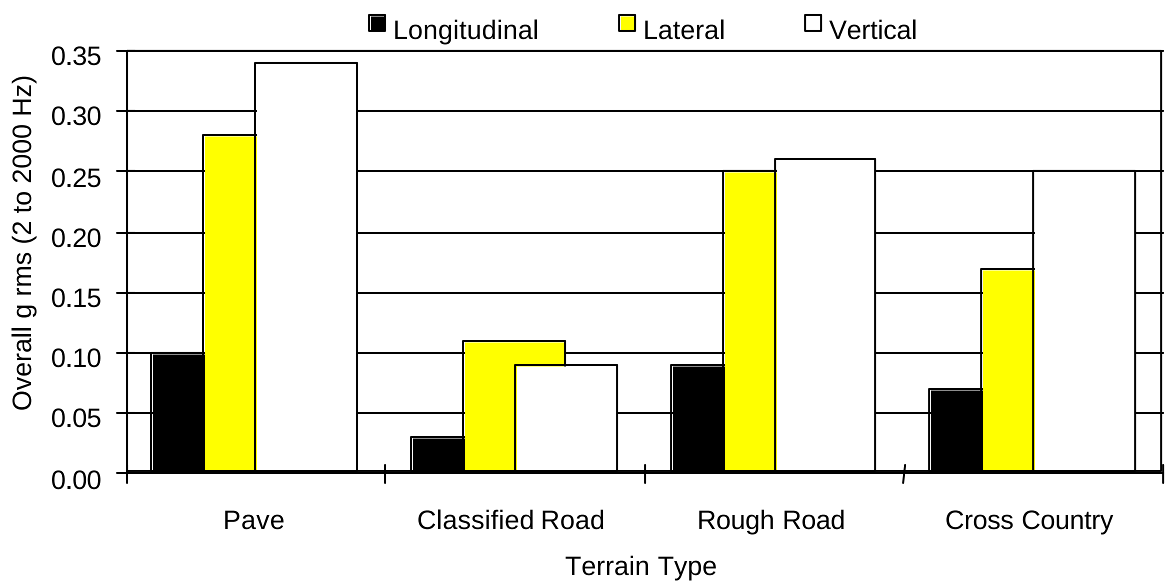
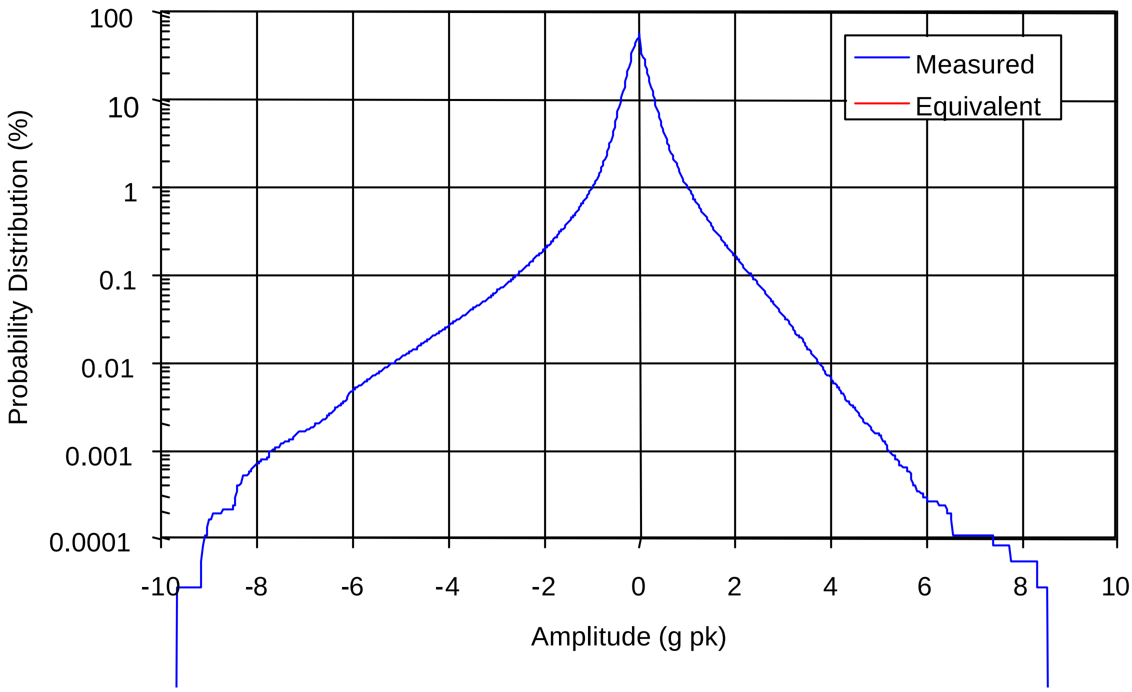
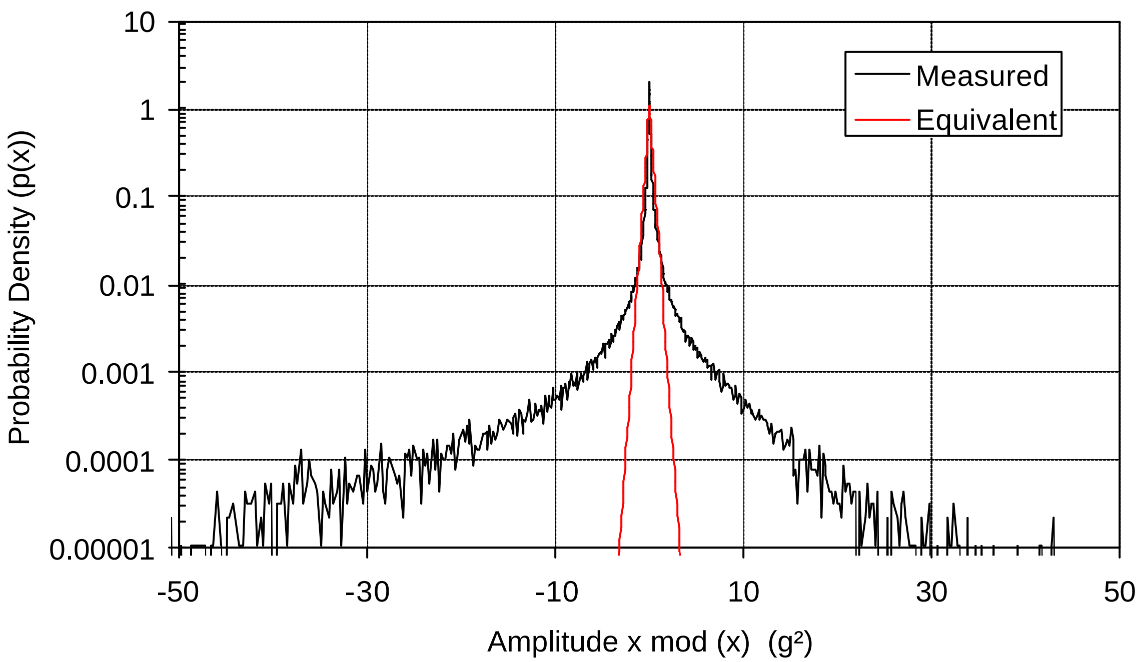


Figure 2 - Effect of terrain on vibration - small four wheel drive vehicle



a. Amplitude probability distribution

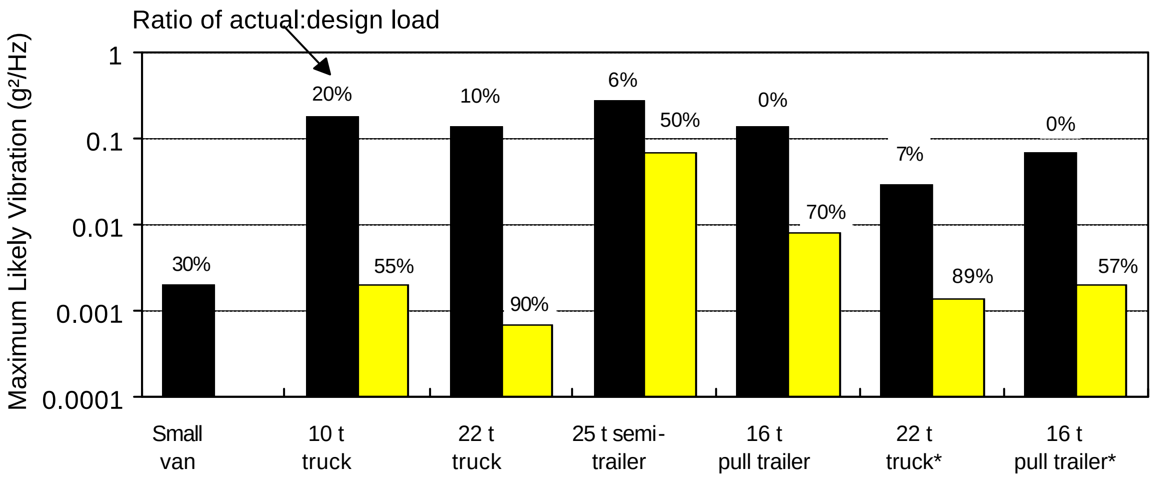


b. Amplitude probability density

Notes:

1. *Measured data are from the load bed (vertical axis) of a 4 t truck on a rough road.*
2. *Equivalent data are from a gaussian distribution of the same rms value as that measured.*

Figure 3 - Measured amplitude probability functions



** These vehicles equipped with air suspension systems*

Figure 4 - Effect of laden weight on vehicle vibration

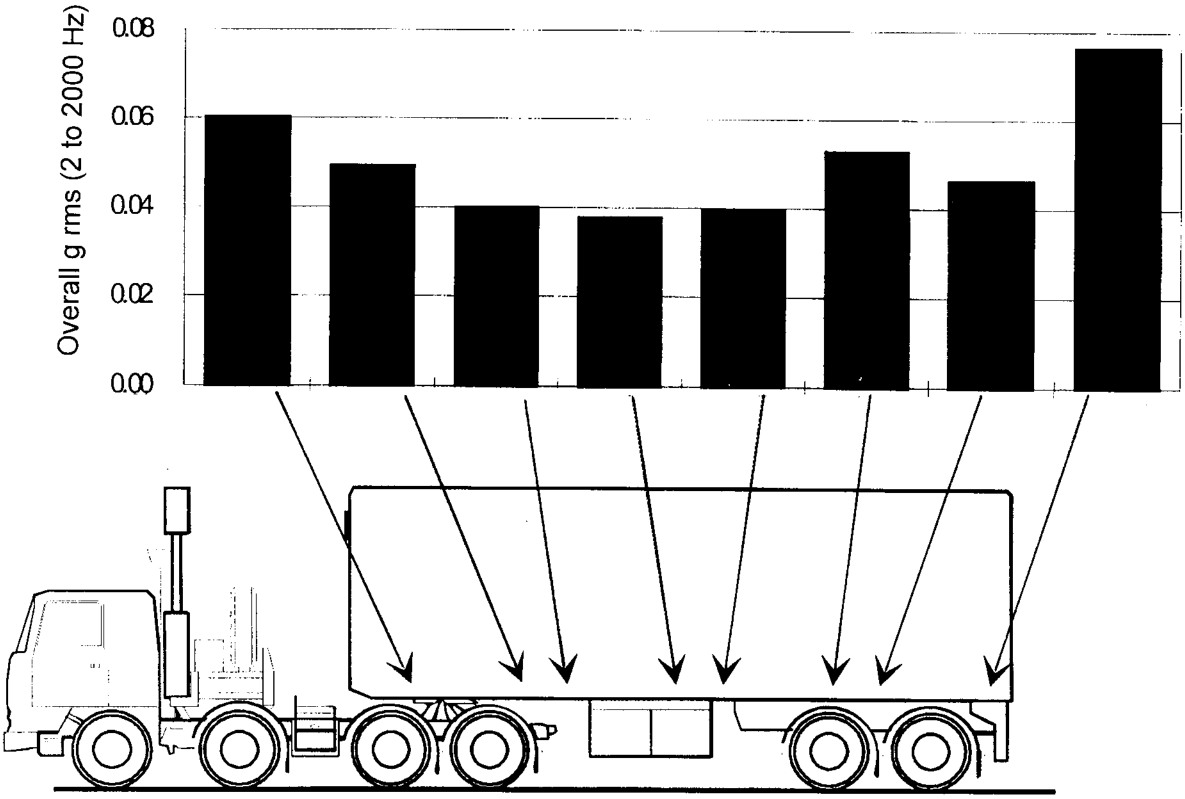


Figure 5 - Articulated trailer vibration amplitudes

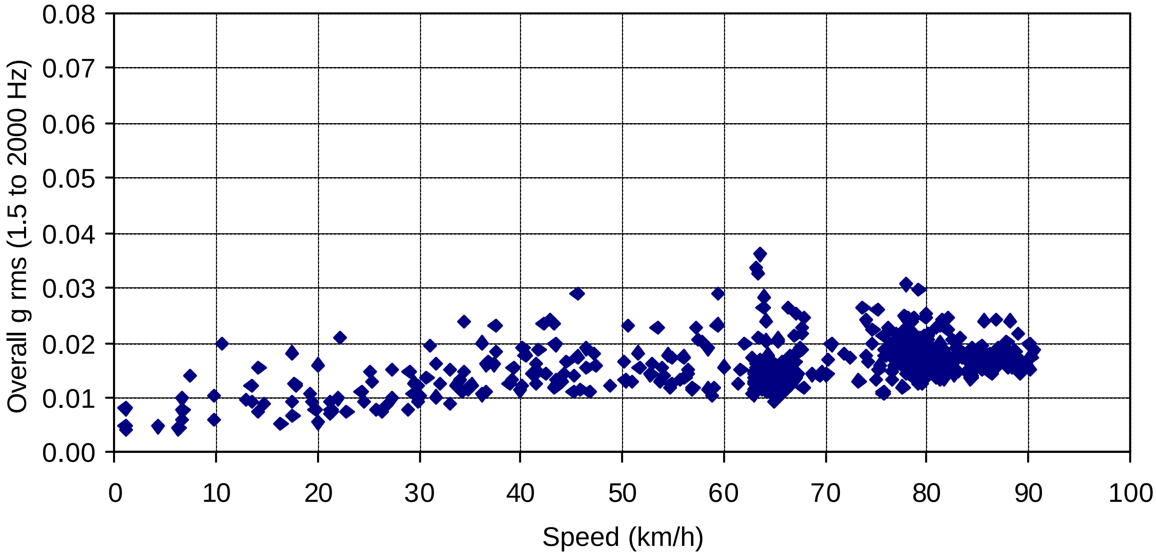


Figure 6 - Vehicle structural vibration versus speed

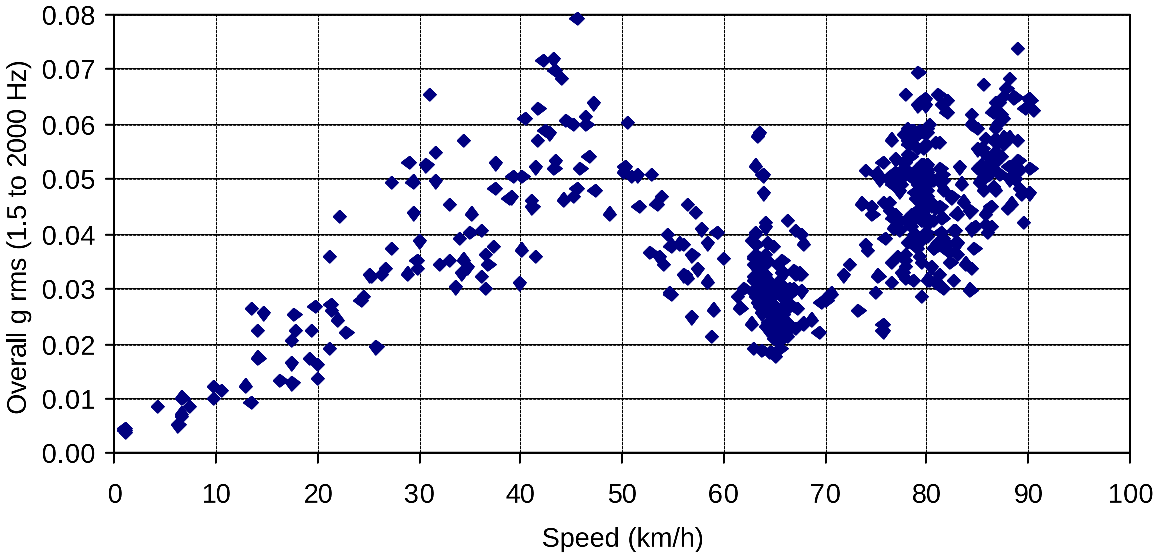


Figure 7 - Equipment vibration response versus speed

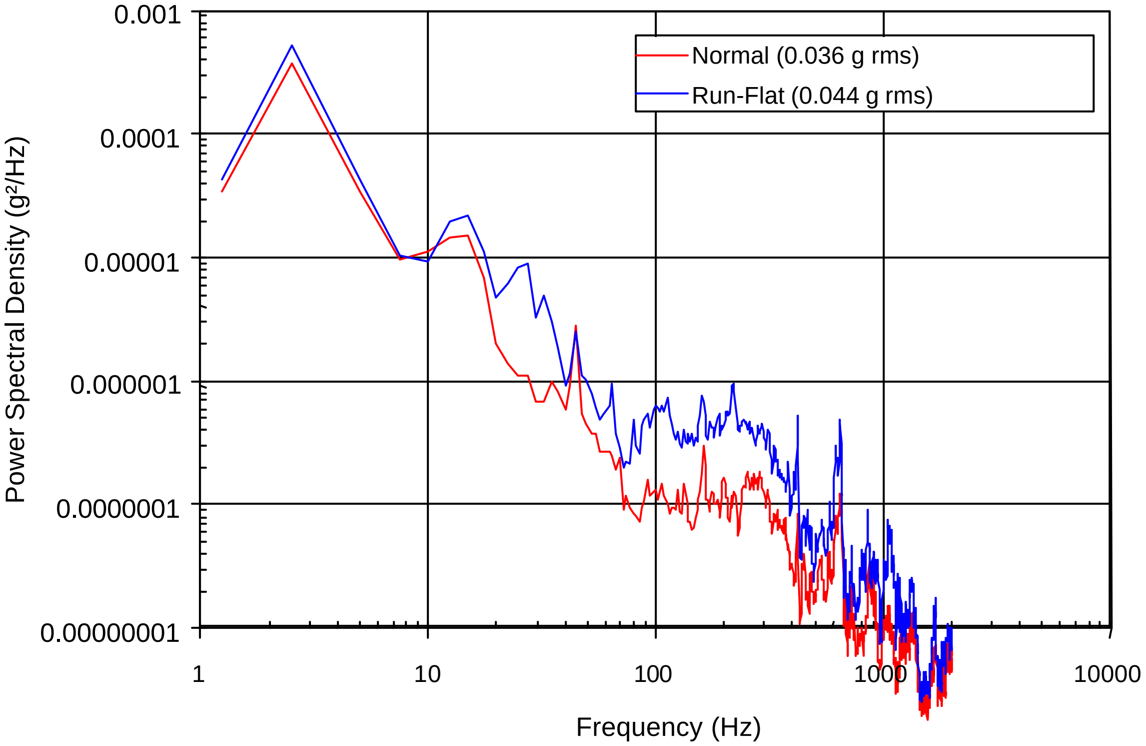


Figure 8 - Effect of deflated tyres on vehicle vibration

SECTION 6

INSTALLATION IN FIXED WING AIRCRAFT

SUB-SECTION 6/1 - INSTALLATION IN JET AIRCRAFT

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel when deployed on or installed in fixed wing jet aircraft. The sources and characteristics of the mechanical environments are presented and where applicable, information is given on potential damaging effects. Additional guidance is contained in Annex A on parameters influencing mechanical environments such as flight vibration and gunfire.

1.2 The following aspects are not included in this leaflet:

a. Materiel deployed on or installed in helicopters. For information on this subject refer to Sub-section 7/1.

b. Engines and associated equipment, ie: the environments experienced by an engine and its associated equipment arising from their own operation. For information on such induced environments, reference should be made to the engine manufacturer.

c. Airframe and other primary structure. For information on loads and severities related to these structures, reference should be made to the aircraft manufacturer.

d. Abnormal conditions, such as crash and blast.

1.3 Unless specified otherwise the environmental descriptions relate to the interface between the aircraft and the installed equipment, and all axes relate to aircraft axes, with the positive longitudinal axis of the right handed axes set coinciding with the direction of normal flight (ie: forward).

1.4 The mechanical environments experienced by materiel installed on fixed wing jet aircraft arise from a wide range of sources. No general rules can be set down as to the dominant source for every item of materiel, especially as some of the potential sources produce very intense but localised effects. For the majority of materiel the most severe continuous conditions arise from only one or perhaps two sources. In addition severe conditions of a transitory nature, can occur due to buffet and the operation of guns. Whilst each application of these transitory conditions may occur for only a few seconds their cumulative effect over the life of the aircraft can be significant.

2. AIRFIELD MOVEMENTS

2.1 Materiel can be expected to experience continuous vibration and transient responses as a consequence of aircraft movements about an airfield. The transient responses are caused by the wheels traversing the inevitable irregularities in the taxi-way surfaces. The severity of these vibrations and transients will be influenced principally by aircraft speed and the size of the aircraft wheels. The responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft.

2.2 As airfield surfaces are usually of good quality and aircraft movements are usually controlled, the severities resulting from airfield movements are usually low and significantly less than those from the flight phase. However, this may not be the case when temporary or repaired taxi-ways are used. In such cases it can be expected that a significant increase in the severity of the transients will occur. However, these conditions are unlikely to be more severe than those occurring during take-off and landing on temporary and repaired runways.

2.3 The motions arising from aircraft movements will result in low amplitude, high frequency of occurrence continuous responses which could cause damage through fretting fatigue mechanisms.

3. TAKE-OFF AND LANDING

3.1 Normal Take-off and Landing Conditions installed materiel.

3.1.1 These transients arise mainly as a result of the aircraft traversing runway surface irregularities at speed. Again, the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft. As both take-off and landing are usually controlled, the amplitudes of the resultant transients are usually benign. Consequently, the dynamic responses experienced during take-off and landing are normally considered to be encompassed within those of the flight phase. Take-off and landing usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. These related aspects are dealt with in paragraph 4.5. Typical take-off vibration severities are shown in Figure 1, whilst typical landing shocks are shown in Figure 2.

3.1.2 The motions arising from normal take-off and landing are largely dictated by the characteristics of the undercarriage system. Therefore, potential damaging effects are likely to be associated with displacements at low frequencies.

3.2 Temporary or Repaired Runways

3.2.1 Continuous vibration and transient shock severities are likely to be more severe when temporary or repaired runways are used. The maximum permitted severity resulting from the use of such surfaces will depend upon the capabilities of the aircraft under consideration and in particular upon the ruggedness of the aircraft undercarriage. Consequently, where necessary, advice on severities should be sought from the aircraft manufacturer. However, any test procedures used to simulate these conditions are likely to be similar to those recommended for normal take-off and landing conditions.

3.3 Catapult Launch and Arrested Landing

3.1.1 Oscillatory transients will be induced in materiel during a catapult launch and/or arrested landing of an aircraft. In general catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events having a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. At installed materiel locations the pulse durations associated with catapult launch and arrested landing are relatively long, and therefore these transients are usually treated as quasi-static conditions.

3.4 Vertical Take-off and Landing

3.4.1 During vertical take-off and/or landing, efflux from the engine nozzles may impinge on parts of the aircraft structure or stores not subjected to such conditions during normal flight. In addition, efflux reflected from the ground may impinge on the majority of the lower aircraft surface. In consequence severe acoustic and vibration conditions may be induced.

3.5 Ski-jump Assisted Take-off

3.5.1 The dynamic environment induced during the use of ski-jump assisted take-off is of very low frequency and is usually considered as a quasi-static, rather than as a dynamic condition.

4. FLIGHT VIBRATION

4.1 Aerodynamic Flow

4.1.1 The most common source of aircraft equipment vibration is associated with airflow surrounding the aircraft. This air flow over the structure may be attached or detached. These two conditions produce significantly different vibration excitations. The more severe vibration conditions are associated with detached flow which exists in areas remote from the leading edge surfaces on all aircraft.

a. Attached Flow: Where the airflow is attached to the aircraft surface a nominally classical boundary layer type flow will exist, and structural vibration can be expected to be at a minimum. Vibration intensity is broadly proportional to the dynamic pressure (q) and the broad band random frequency spectrum is related through Strouhal Number with the boundary layer thickness and velocity.

b. Detached Flow: Where detached flow exists the intensity of the pressure fluctuations can rise to typically five times those associated with attached flow. In addition, the area over which the fluctuations are correlated increases by several orders. This increase in area has the potential to significantly increase the effectiveness by which the flow can excite the structure. The increased pressure fluctuations will continue to relate with dynamic pressure “q” (but with a higher coefficient of efficiency) and the frequency scaling will continue to relate with Strouhal Number. In practice the increased pressure fluctuations will result in increased structural vibration responses over a broad frequency range whilst the increase in area of correlated pressures may result in a very significant increase of structural vibration responses over narrow frequency ranges.

4.1.2 Vibration arising from aerodynamic turbulence can generate brinelling, fretting, and high cycle fatigue. The parameters influencing flight vibration levels are discussed in Annex A.

4.2 Vortex Impingement

4.2.1 On high performance aircraft under certain conditions of angle of attack, heading and airspeed, it is possible for vortices originating from parts of the aircraft to impinge on downstream structure. The characteristics of these vortices are such that severe structural vibrations may arise. In general these vibrations may be dominated by the lower structural modes of the particular portion of the airframe (wing, empennage etc). The severe vibratory conditions are transitory in nature and rarely occur for more than a few seconds at any one time. However, during the life of an aircraft the total number of such occurrences may be significant. The resulting vibration characteristics, severities and areas of airframe affected will be unique to aircraft type. An example of the responses due to vortex impingement is shown in Figure 3.

4.2.2 The potential high levels of vibration, coupled with the knowledge that the dominant structural responses occur at the lowest structural modes, the most likely damage effects are those associated with high acceleration loadings and low to medium cycle fatigue.

4.3 Buzz

4.3.1 This condition is sometimes categorised as a type of single degree of freedom flutter. However, whereas conventional flutter is associated with the generalised aerodynamic flow over the wing (or control surface), buzz is normally associated with shock wave oscillation and the induced structural oscillation is of a higher frequency than occurs with conventional flutter. To aircraft structure, the phenomenon will appear as a good quality sine wave, with some amplitude modulation, at a frequency of typically 60 Hz.

4.4 Engine Intake Flow Effects:

4.4.1 Variable intakes can have a geometry such that the main flow into the intake can pass over a cavity used for ducting away excess air. Experience has shown that strong acoustic discrete frequency resonances can occur in the duct which can in turn produce high strain levels in the duct structure and any splitters or guide vanes in the duct. Vibration responses from this source have been noted in wing structure, installed equipment and stores. Neither the intensity nor the frequency of excitation can be calculated with much accuracy because the effective dimensions of the duct space cannot be determined accurately.

4.5 Powerplant Effects:

4.5.1 Powerplant induced vibration in aircraft installed equipment is predominantly due to impingement of engine noise on the aircraft structure. It can also arise as a result of the local “attachment” of a jet plume to the aircraft structure. Sources of jet noise are described below.

a. Jet Noise Mixing: The noise created by the turbulent mixing of an issuing jet (jet noise) has been troublesome and a prime source of structural vibration which has affected many aircraft. The usual effect is to produce long-term fatigue in cleats, corners of stringers, ribs and, more frequently, under rivets. In severe noise fields, over 160 dB, shorter term fatigue can occur in more important structural locations, such as rib webs and at the centre of panels. At higher levels still, over 170 dB, failures in prime structure can occur in conventional designs. In such cases special features may need to be incorporated into the design. The problem was recognised early and much theoretical and experimental work was done to combat the problem. Today it is assumed that adequate attention is given to detail design and to the use of certain basic rules in order to alleviate these problems. Extensive literature exists on these aspects.

b. Choked Jets: In an under-expanded supersonic jet, shock cells exist which, relative to a subsonic jet, results in an increase in the spectral density of the random pressure fluctuations in a particular region of the frequency spectrum. These particular frequencies are associated with the dimensions of the shock cells which can change during flight if the jet pressure-ratio changes. There have been cases where the frequency of the spectral peak has coincided with the frequency of structural panels and damage has resulted.

c. Jet Attachment: A jet which is close, but nominally clear of a structure can attach itself to the structure by a mechanism which is sometimes referred to as the Coanda effect. This occurs when due to a manoeuvre or a change in the jet dimensions as a result of a pressure-ratio change (eg: altitude), the boundary conditions required for the full mixing of the jets are not met. This will occur for instance when the necessary full air-entrainment on one side of the jet is restricted as the jet moves towards the fuselage. The jet will then move further towards the fuselage so that the boundary-layer existing on the fuselage and the flow at the jet edges will merge “sucking” the jet towards the fuselage so that it eventually sticks to it. This produces an upward and sudden step in the level of vibration and noise, as well as producing a heating effect.

4.5.2 As the character and structural response mechanisms of the vibrations attributable to these powerplant effects are similar to those from aerodynamic turbulence, similar failure mechanisms are likely to result.

4.6 Cavities

4.6.1 Cavities exposed to a grazing airflow passing the aircraft can be a significant source of both noise and vibration. The frequency spectrum of such disturbances can be wide in range and usually features sharp peaks and troughs over the frequency range. The main peaks arise from the excitation of acoustic “space” modes which are a direct function of the dimensions of the cavity. A bomb bay is an obvious example of such a cavity. The frequencies of the main modes can be calculated with some confidence from standard formulae. The majority of the less dominant modes are usually harmonics of the main modes and can persist up to quite high orders. The amplitudes of the pressure fluctuations are less easily estimated because they are affected by geometrical factors such as the sharpness of the edges of the cavity, the direction of flow over the cavity and the contents of the cavity. The contents of the cavity can have the effect of making the main modal peaks less discernible whilst increasing the level of the background broad-band “noise” which is always present.

4.6.2 The most likely damage effects associated with cavity resonances are those associated with high acceleration loadings and medium cycle fatigue.

5. FLIGHT MANOEUVRES AND GUSTS

5.1 Materiel will experience low frequency acceleration loadings due to flight manoeuvres and gusts. These are normally considered as quasi-static loadings for design and test purposes. At a particular aircraft location the loadings arise mainly from the vector sum of the six “rigid body” aircraft degrees motions, ie: vertical, lateral, longitudinal, roll, pitch and yaw. In some cases these could be amplified by the dynamic motions of the lower aircraft modes.

5.2 The severity of the flight acceleration environment will depend mainly upon the type of aircraft under consideration. Generally the flight accelerations are a specified design requirement for a particular aircraft type and hence are well defined early in a design. These accelerations are usually constrained by flight limits or the aircraft control system. In some instances these loadings are monitored for fatigue purposes.

5.3 The most probable damaging effect is that due to acceleration loadings producing internal forces within the equipment, often at its mountings, of sufficient magnitude to cause structural or fatigue failure. In some cases such loadings may cause deflections of sufficient magnitude to prevent the proper operation of mechanisms.

6. GUNFIRE

6.1 Significant vibration and shock excitations in aircraft structure, installed equipment and stores can arise from the operation of guns situated either within the aircraft or in external pods. Whilst the total duration of these excitations is relatively short the amplitudes can be several orders of magnitude greater than the vibrations arising during normal flight. Moreover, the characteristics of the responses can be significantly different to the vibrations occurring during normal flight conditions and may induce different equipment failure modes.

6.2 he effects of gunfire potentially induce vibrations from three different sources. These are overpressure or blast emanating from the gun muzzle, recoil of the gun on its mounts and motions of the ammunition and its loading system. Usually the most significant of these on installed equipment is that due to blast, which produces the most widespread vibration effects on structure and equipment.

6.3 Gun blast overpressure is created by the sudden expansion of the propellant gas from the muzzle after the projectile emerges. This gun blast propagates through the air and impinges on the surrounding structure. The pressure wave may affect equipment directly or indirectly via the aircraft structure. The severity of the pressure waves is dependent upon a number of factors such as altitude, airspeed, type of gun and ammunition, distance from the muzzle and the incidence of the blast wave. These factors and a method for computing the magnitude of the blast pressure wave impinging on the surrounding structure are detailed in UK Defence Standard 00-970, Volume 1, Sub-section 501/5.

6.4 The character of structural responses arising from gun blast will depend upon the location of the structure or equipment with respect to the gun muzzle. These responses can be considered to have distinctly different characteristics in each of the near, middle and far spatial fields.

a. Near Field: The character of structural responses arising from gun blast near the gun muzzle, ie in the near spatial field, is largely influenced by the impulse of the blast pressure wave. Structural and equipment responses will appear as a sequence of distinct shock pulses. The near spatial field will include the muzzle breakout point and structure in its immediate vicinity. In the absence of a spatial definition the near field should be considered to be a circular area of 0.5 m^2 extending around the gun muzzle in the plane normal to the gun muzzle. When uncertainty exists as to whether equipment is located in the near or middle fields, and particularly for equipment critical to aircraft safety, the near field should be assumed.

b. Middle Field: The response of structure and equipment more distant from the gun muzzle, ie in the middle spatial field, is largely influenced by the coupling of the pressure pulse with the dynamic characteristics of the structure. The character of the response is dominated by the periodic motions arising from the gunfire rate and its subsequent harmonics. If no better information is available, the middle spatial field should be considered to extend beyond the near field up to 150 calibres from the muzzle. When doubt exists equipment and structure should be considered to be located in the middle field in preference to the far field.

c. Far Field: For equipment and structure well away from the gun muzzle the vibrations arising from gunfire overpressure may not be readily discernible within the normal flight vibration levels. The higher harmonics of the gunfire rate tend to become less significant eventually leaving only the periodic motions at the fundamental gunfire rate. In the far spatial field because the amplitude of the responses from gunfire are less than those form normal flight aerodynamic excitations, the difference in character is unlikely to have a significant effect. The far field encompasses all the remaining zones of the aircraft not considered as near or middle field.

Further information is given in Annex A.

6.5 Vibrations arising from gun recoil tend to be less severe than those from blast. This is because the effects of gun recoil tend to be filtered by the high gun mass and mount stiffness effective at the gunfire frequency. Consequently gun recoil usually only significantly affects equipment close to the gun mounts. The vibrations due to ammunition loading and handling systems are the least significant of the three potential sources. This source only effects equipment very close to the handling system. However, it is likely to be a significant source for the ammunition itself.

6.6 In the near field the amplitude of the blast pressure wave may be sufficient to cause structural failure of panels and their supports. Equipment in close proximity to the muzzle, but protected from the direct blast pressure wave, may fail due to the severity of the discrete and repetitive shock pulses. The most likely failure modes of equipment in the middle field are those associated with high intensity, low frequency vibration.

7. LAUNCH OF WEAPONS

7.1 The launch or firing of weapons (excepting gunfire) can, in certain circumstances induce high level of shock, vibration and pressure blast in the aircraft structure and equipment, nearby weapons or stores.

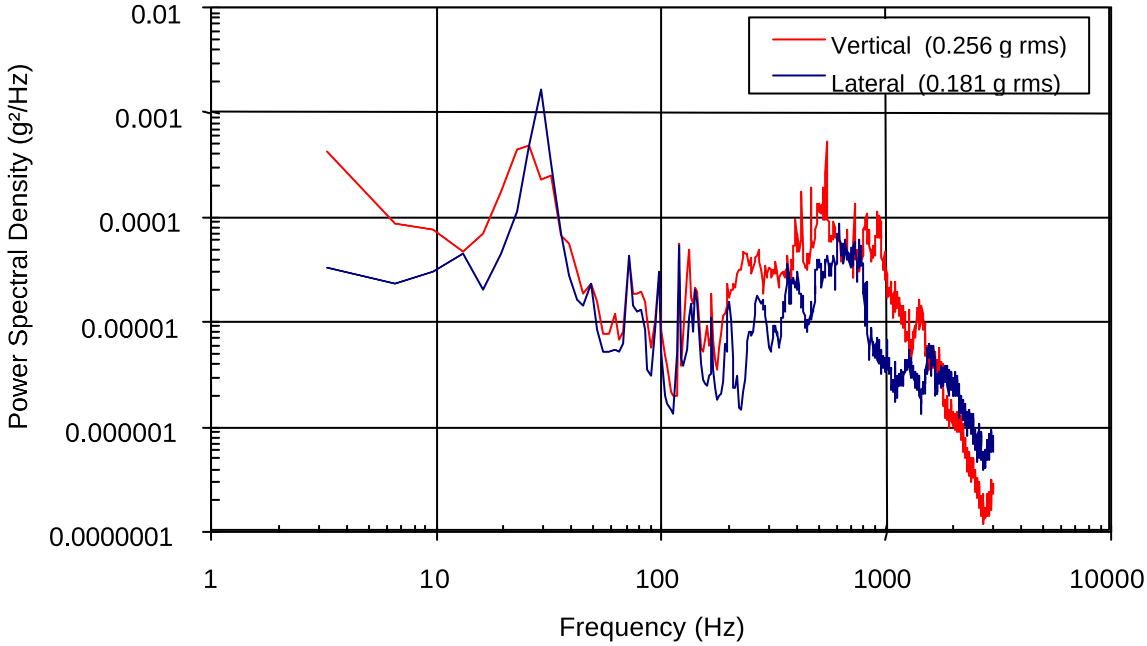


Figure 1 - Vibration occurring during take-off

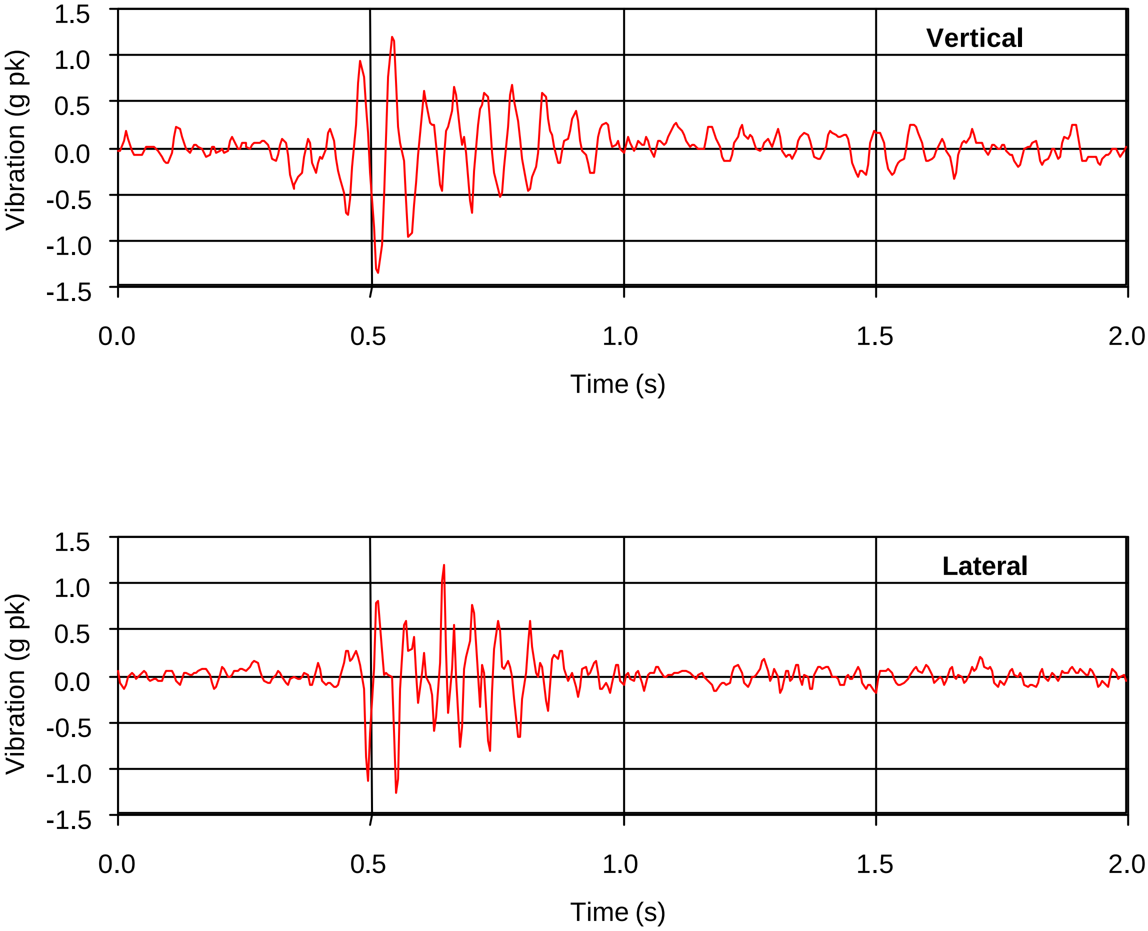


Figure 2 - Transients occurring during a normal landing

PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 Flight Vibration

A.1.1 Flight measured vibration data will rarely be available for all in-service conditions, therefore it is useful to establish, where practicable, a working knowledge of the effects of various parameters on vibration severity. This is usually achieved by the derivation of empirical predictive models from measured data acquired from a well planned programme.

A.1.2 Experience indicates the following parameters and trends are worthy of consideration.

a. Altitude and Airspeed: An important parameter influencing vibration severity is flight dynamic pressure; which in turn is related to altitude and airspeed. This parameter is particularly significant when considering severities for high performance jet aircraft. Investigations may be undertaken by examining plots of overall root mean square (rms) vibration versus flight dynamic pressure.

b. Powerplant Demand: Variations in this parameter and its effect on vibration severity may be especially appropriate for VSTOL aircraft.

c. Axis and Location: Investigations of the general variations in vibration responses by axis and location is particularly useful for the cargo areas of transport aircraft. The variations can be examined in terms of overall rms vibration and spectral profile. It may also be applicable to establish the general trend of vibration levels around the aircraft. Establishing a precise description is unlikely to be practicable due to the complicated nature of the structural dynamic characteristics. However, such precise descriptions are rarely necessary in practice.

d. Payload Configuration: The effects of payload configuration (total mass and distribution) on vibration levels may be investigated where significant variation in payload configuration is likely to occur. These effects can also be examined in terms of overall rms vibration and spectral profiles.

e. Vortex Impingement: The effects of vortex impingement can be examined using plots of peak amplitudes in the time domain. However, the onset and magnitude of the vibration responses cannot be readily correlated with the usual monitored aircraft parameters. Moreover, the effects of vortex impingement are difficult to model using empirical prediction techniques.

f. Flight Manoeuvres: These can include non-stationary conditions such as take-off, landing, reverse thrust, wind-up-turns, etc. In these cases, plots of overall rms vibration versus time are usually appropriate.

g. Mach Number: Whilst the effects of airspeed are normally related to flight dynamic pressure, in some instances the relationship may change at higher Mach numbers. Consequently it is prudent to establish the relationship between vibration severity and Mach number in addition to the more usual relationship with dynamic pressure.

A.2 Gunfire

A.2.1 The parameters examined will depend upon the proximity of the equipment to the gun muzzle, ie: whether it is located in the near, middle or far fields.

a. Near Field: In the near field the blast pulse will almost certainly be the dominant feature in the measured dynamic responses. Moreover, the preferred test will consist of reproducing this pulse. Hence the extraction of the characteristics of the pulses will be the prime concern. This is probably best achieved in the time domain as the use of either frequency spectra and shock response spectra will cause problems due to the presence of the background aerodynamically induced broadband random vibrations.

b. Middle Field: In the middle field equipment responses will be dominated by structural responses rather than by the blast pulses. As the simulation is usually a broadband random it is appropriate to evaluate the measured responses in the frequency domain. The nature of the responses will be broadband random with superimposed “near periodic” components at the gunfire rate and subsequent harmonics. Accurate determination of these latter components may require very narrow bandwidth analysis which may be incompatible with the identification of the broader frequency range random vibration. Under such circumstances separate frequency spectra aimed at quantifying each aspect separately may be needed. Even then it may be prudent to use mean square values to quantify the individual harmonics.

c. Far Field: As gunfire is unlikely to cause problems in the far field no specific recommendations are offered.

SUB-SECTION 6/2 - EXTERNAL CARRIAGE ON JET AIRCRAFT

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by stores during external carriage on fixed wing jet aircraft. The sources and characteristics of the mechanical environments are presented and described, and where applicable, information is given on potential damaging effects. Guidance in given in Annex A on the parameters influencing store vibration.

1.2 Environments associated with store separation from the aircraft are covered in Sub-section 9/1 - Air and land weapons. Environments associated with the aircraft itself are covered in Sub-section 6/1 - Installation in jet aircraft.

1.3 The vibration experienced by stores during externally carriage on high performance jet aircraft is relatively high. As a consequence considerable testing is usually necessary to ensure that the store is capable of meeting its in-service requirements.

1.4 Many aspects influence store vibration under external carriage conditions, and in view of the associated high severities, it is important to acquire an understanding of the major influences that could affect the vibration severities of a particular store/aircraft configuration in order to derive an effective test specification. The following paragraphs introduce these major influences and discuss their associated vibration characteristics and severities.

2. TAXI-ING, TAKE-OFF AND LANDING

2.1 Normal Conditions

2.1.1 During taxi-ing, take-off and landing oscillatory transients may be induced in a store and its equipment. These transient arise as a result of the aircraft traversing the taxi-ways and runways. Generally the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft as well as the lower suspension modes of the store. These transients are usually relatively benign and encompassed within those of flight carriage. The severities are likely to be more severe when temporary or repaired taxi-ways and runways are used. Take-off usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. The noise levels may be greater than those of flight because of the effects of ground reflection.

2.2 Reverse Thrust Devices

2.2.1 Some aircraft utilise reverse thrust devices during landing. These devices not only involve high levels of engine power but may also redirect the engine efflux back towards the aircraft. This can produce particularly high levels of localised acoustic noise and vibration, albeit for only a few seconds. Figure 1 shows the characteristic responses from the rear of a store as a result of impingement of redirected engine efflux occurring during the operation of a reverse thrust device.

2.3 Catapult Launches/Arrested Landings

2.3.1 Short duration oscillatory transients will be induced in a store due to an aircraft catapult launch or an arrested landing. In general a catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events having a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. Whilst the pulse amplitudes associated with catapult launch/arrested landing are low, the long (several seconds) periods of application and high frequency of occurrence have the potential to cause damage.

2.4 Vertical Take-Offs and Landings

2.4.1 During vertical take-off or landing efflux from the engine nozzles may impinge on stores not normally subjected to such conditions. In addition, and probably more importantly, jet efflux reflected from the ground may impinge on the majority of the lower aircraft surface including stores. In consequence severe vibration conditions unique to vertical take-off and/or landing may be induced.

2.5 Ski-jump Assisted Take-Off

2.5.1 The dynamic environment induced during the use of ski-jump assisted take-off is of very low frequency and usually considered as a quasi-static aircraft loading condition rather than as a vibratory or transitory one.

3. FLIGHT OPERATIONS

3.1 General

3.1.1 The mechanical environments experienced by externally carried stores during flight carriage on fixed wing jet aircraft are mainly vibratory and originate from the relatively steady aerodynamic flow traversing the store external surface. However, under certain flight conditions, other sources such as buffet manoeuvre, may induce responses even more severe than those from steady state aerodynamic flow. Both conditions are addressed below, together with vortex impingement and jet noise. Further detailed information on the effects of aerodynamic flow, buzz, engine intake flow, powerplant can be found in Sub-section 6/1. Also the effects of manoeuvres and gusts, and structural cavities are fully covered in Sub-section 6/1 and therefore are not repeated under this heading.

3.1.2 The physical parameters of a store and its deployment configuration can significantly influence vibration responses, although it is usually impractical to quantify their interaction with the applied unsteady aerodynamic pressures to predict vibration responses. The influence of the major parameters, which include dynamic pressure, store type, location etc, on vibration severities are discussed in Annex A.

3.2 Aerodynamic Flow

3.2.1 The most significant source of store vibration is associated with the unsteady pressures in the airflow surrounding the store. The airflow over the store, particularly over the forward regions, may be smoothly attached to the store, or it may be detached, as it usually is over the aft regions of a store. The more severe vibrations experienced by stores are associated with detached flow.

3.2.2 The effects of attached and detached flow are demonstrated in Figure 2. The dotted curve indicated responses when the flow is mainly attached, whilst the solid curve shows the effects following the onset of detached flow. Corresponding wind tunnel measurements indicate that unsteady pressures increase by a factor of between 2 and 2.5 over a broad frequency range. These increased pressures can result in significantly increased vibration responses of panel modes, as indicated in Figure 2.

3.2.3 As the vibration excitation arising from the normal aerodynamic flow over the store is essentially broad band random vibration, damage effects are likely to be fatigue related, such as the fretting failure of small mechanisms, electrical connections, etc. For high modal density stores the frequency range of excitation is such that modes of vibration up to at least 3 KHz are excited; the highest vibration amplitudes often occurring around the store ring mode frequencies. For low modal density stores the responses may be dominated by only a few frequency peaks; but the vibration amplitude at each peak is likely to be relatively high.

3.2.4 Further details on aerodynamic flow are given in Sub-section 6/1, paragraph 4.1.

3.3 Vortex Impingement

3.3.1 At certain aircraft manoeuvre conditions, it is possible for vortices originating from, say, the air intake of a high performance aircraft to impinge on a downstream store. During these conditions severe transitory vibration responses can be generated but rarely occur for more than a few seconds at any one time. The characteristics of the vibration responses are unique to the particular store/aircraft installation, and may only occur during a very limited range of combinations of airspeed, attitude, heading and angle of attack. Should the vortex frequency coincide with a local resonance, high amplitude vibration would occur which might result in fatigue damage.

3.4 Buffet Manoeuvre

3.4.1 When the vortex impingement conditions described in paragraph 3.3 excite the fundamental modes of a wing mounted store, or the rigid body modes of a wing mounted store on its relatively flexible carriage equipment, very severe vibration responses can be generated. Typical comparative vibration responses are shown in Figure 3 of a wing mounted slender missile on a high performance aircraft during straight and level flight and when undertaking a wind up turn. The dominant vibration response around 30 Hz is the missile's fundamental bending mode.

3.4.2 For relatively long and slender missile systems, the vibration response levels at the affected modal frequencies can be the most severe the system will experience during its operational life. Due to the non stationary data characteristics for these buffet conditions it is difficult to assign amplitudes with any confidence, but at the forward section of a slender missile system vibration responses have been observed that exceed 10 g in the time domain and 10 g^2/Hz in the frequency domain. Moreover, although the high vibration responses only occur for a few seconds during each buffet manoeuvre condition, the resulting amplitudes at relatively low frequencies can generate sufficient displacements that, when coupled with their potential frequency of occurance, can adversely influence the fatigue life estimates for the missile structure.

3.4.3 Similar buffet manoeuvre conditions can arise from rigid body motions of a wing mounted store or missile resulting from aircraft wing bending or torsion. Comparable vibration amplitudes under such conditions for a 1000 lb store during straight and level flight and when undertaking a wind up turn are shown in Figure 4, where store responses in the vertical axis of the stores cg are seen to increase by more than three orders of magnitude at low frequency. The response at around 25 Hz is attributed to a wing torsion mode. Further studies on this response indicate that it is related to angle attack and dynamic pressure as shown in Figure 5. Vibration responses are more pronounced for forward mounted slender missiles on outboard wing stations and can attain amplitudes comparable with those cited in the previous paragraph.

3.5 Jet Noise

3.5.1 Power plant induced vibration in externally carried stores arises predominately from the noise generated by the turbulent mixing of the issuing jet, reflecting from the ground during take-off. Resulting store vibration amplitudes are usually less than those induced from high speed flight, but could be the dominant vibration source for stores carried towards the rear of low performance aircraft. The characteristic of this vibration is usually wide band random. Further details on powerplant effects are presented in Sub-section 6/1 paragraph 4.5.

4. GUNFIRE

4.1 Significant vibration and shock responses can arise in externally carried stores due to the operation of guns installed within the carriage aircraft or in adjacent external pods. Whilst the total duration of these excitations is relatively short, the amplitudes can be significantly higher than the vibrations arising during normal flight. Moreover, the characteristics of the responses are significantly different to the vibrations arising from normal flight conditions and may induce different failure modes.

4.2 The effects of gunfire potentially induce vibrations from three different sources. These are the overpressure or blast emanating from the gun muzzle, the recoil of the gun on its mounts and the motions of the ammunition and its loading system. For externally carried stores the most significant of these is almost always that due to blast. Typical vibration responses of a store skin panel and internal equipment due to gunfire blast effects are illustrated in Figure 6. Further information on the treatment of gunfire effects for all three sources is given in Sub-section 6/1 - Installation in jet aircraft.

5. LAUNCH OF WEAPONS

5.1 The launch of weapons can induce high levels of shock, vibration and pressure blast in nearby stores. In most cases the induced loadings are considered as quasi-static conditions and are dealt with accordingly. In some cases they can induce low frequency dynamic responses of the aircraft wing structure, which in turn may produce high store loads. Store attachment arrangements have been known to fail under such loads. Additional shock, vibration and/or pressure blast testing may be necessary to simulate these effects, but as these loading conditions are project specific it is inappropriate to offer general advice.

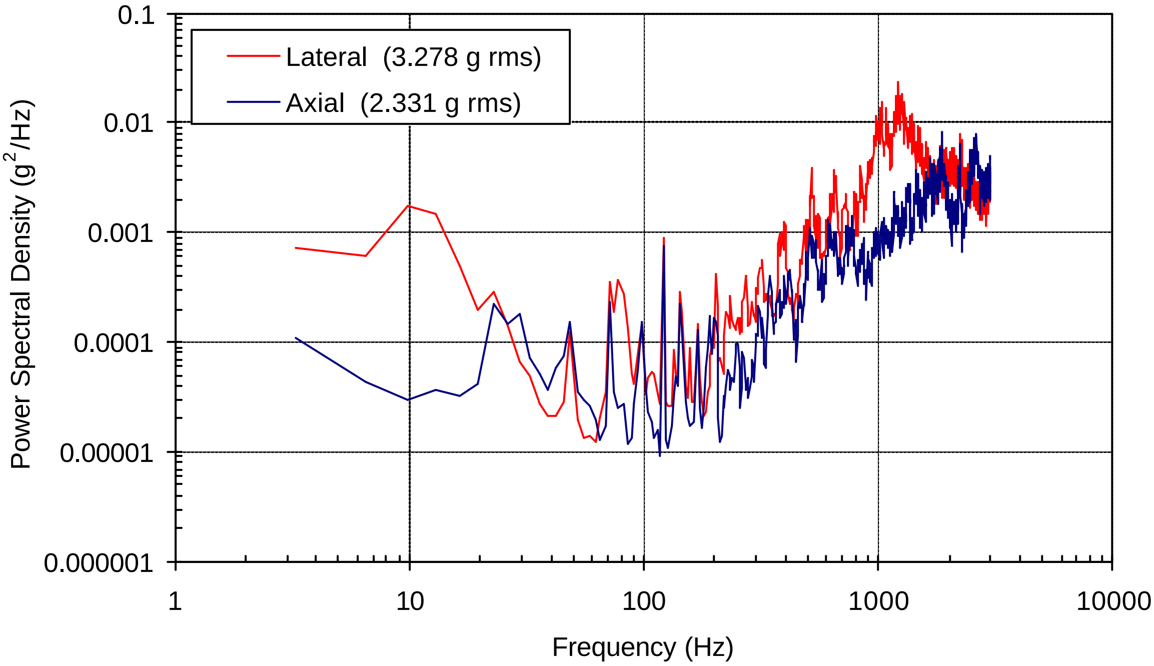


Figure 1 - Vibration response of a store panel directly ahead of aircraft engines during reverse thrust

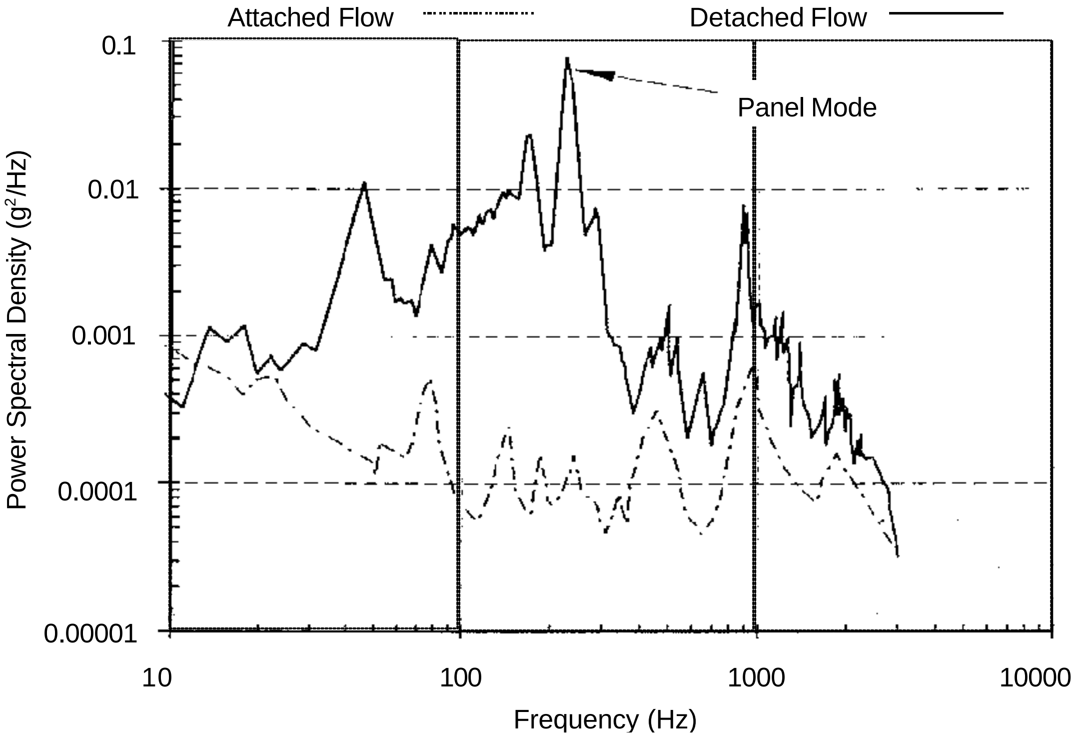


Figure 2 - Effects of attached and detached flow on store vibration responses

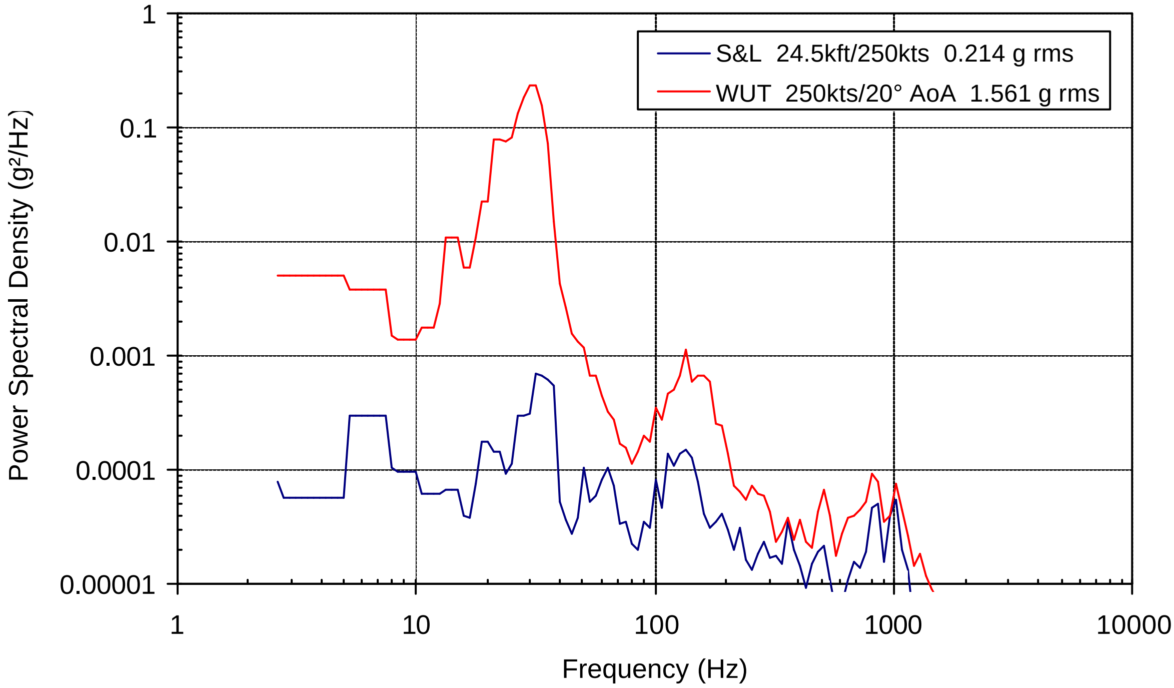
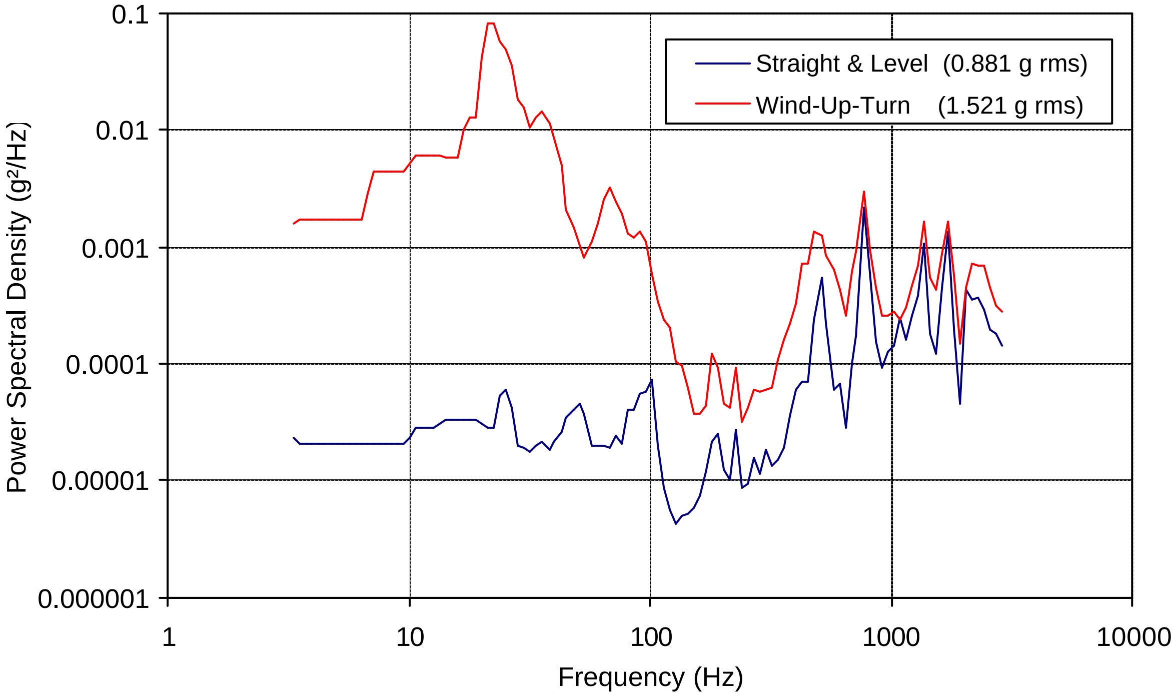
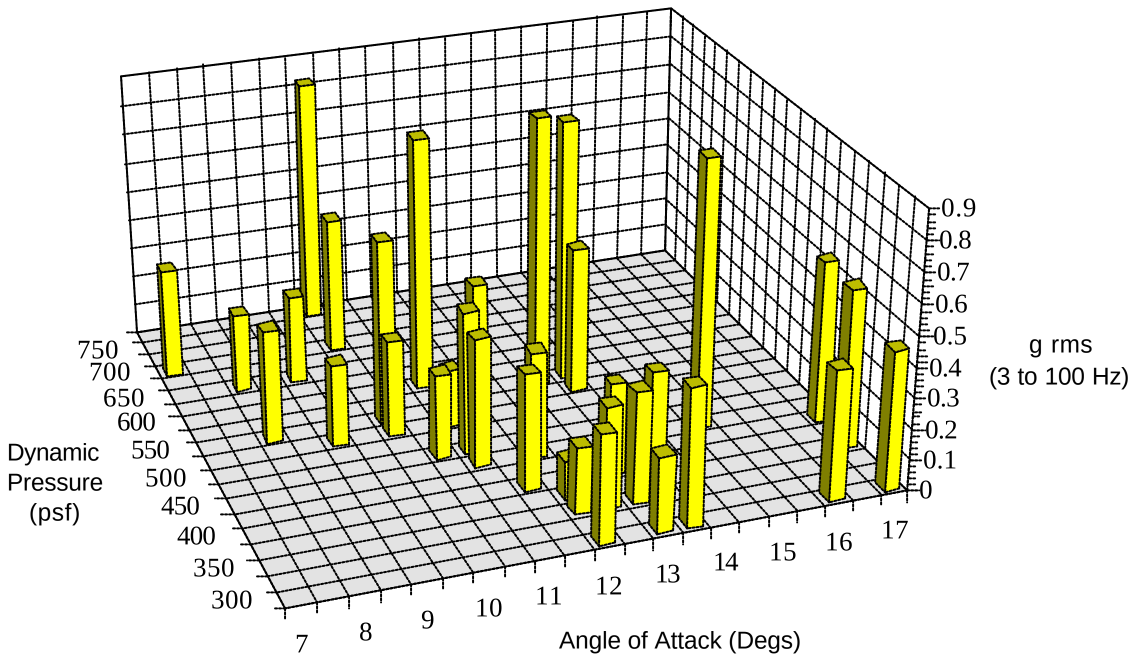


Figure 3 - Comparison of vibration of a slender missile during straight and level flight and in buffet on a fast jet aircraft



Note: Both manoeuvres flown at a dynamic pressure of 420 psf

Figure 4 - Comparison of store vibration in straight and level flight and in buffet at 420 psf on a wing pylon on an agile fast jet

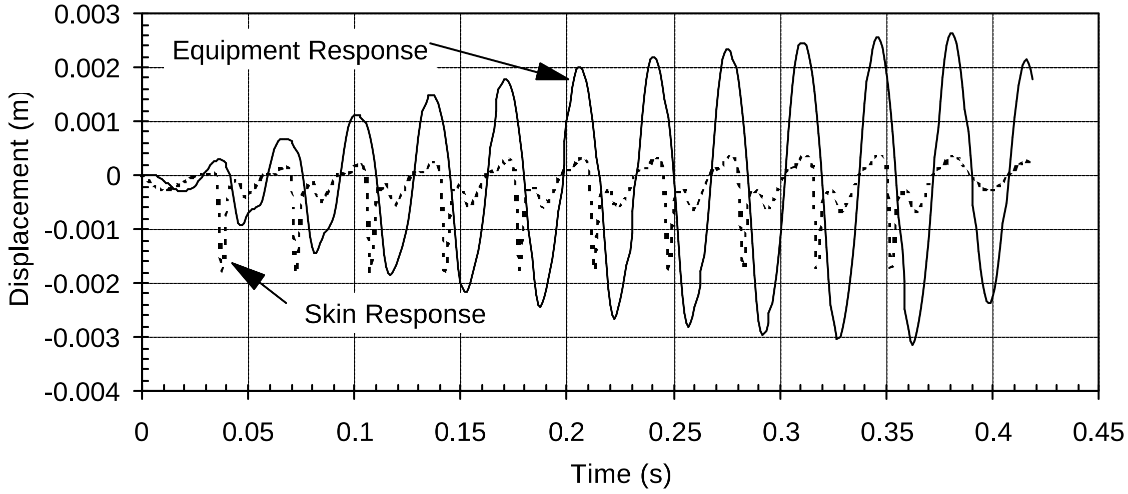


Notes:

1. *Data acquired over the frequency range where store buffet was known to occur, ie: 3 to 100 Hz*
2. *Data were acquired under stationary conditions of buffet*
3. *Store externally carried on a wing pylon of an agile fast jet*

Figure 5 - Store vibration as a function of angle of attack and flight dynamic pressure

Displacement Response to Applied Gunfire Burst (10 rounds)



Acceleration Response to Applied Gunfire Burst (10 rounds)

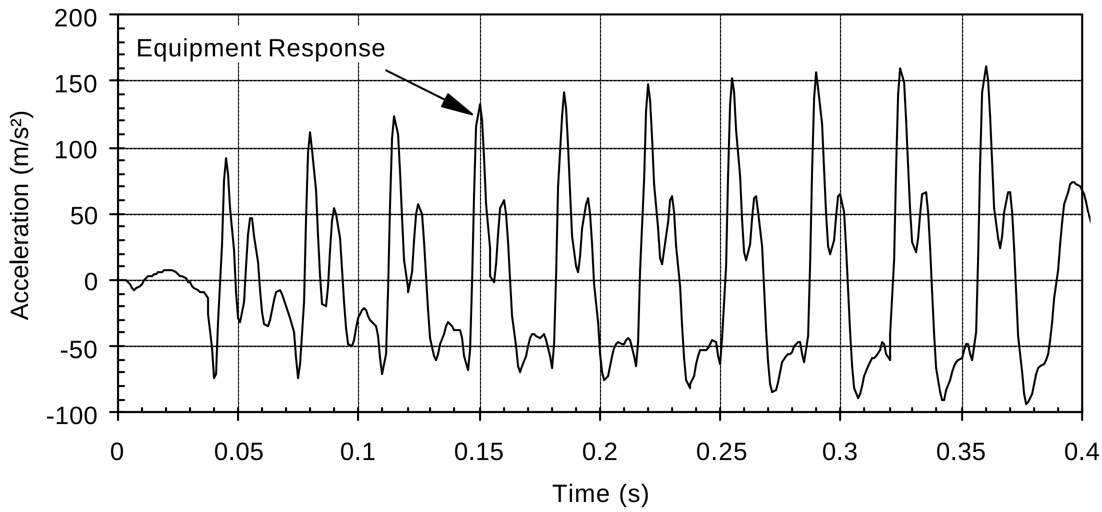


Figure 6 - Vibration responses of a store skin panel and internal equipment due to gunfire.

PARAMETERS INFLUENCING STORE VIBRATION

A.1 General

A.1.1 This Annex provides information on the influence of store properties, store deployment conditions and aircraft flight conditions on vibration severity.

A.2 Dynamic Pressure

A.2.1 The intensity of store vibrations arising from the relatively steady flow traversing the store external surface has been shown to be related to dynamic pressure. Moreover, provided that the flow regime around a store remains reasonably stable the relationship between store vibration and dynamic pressure can be quantified with a high degree of confidence. Knowledge of this relationship is particularly important, because it can be applied very effectively to estimate vibration severities. A typical dynamic pressure versus vibration severity relationship for external stores is shown in Figure A1.

A.3 Store Type

A.3.1 Store type, in terms of both shape and construction, is one of the most influential parameters effecting vibration severity. The variation in store responses is illustrated in Figures A2 to A5. The store responses are from similar locations on four different stores normalised to the same flight conditions. Although store type is one of the most important aspects influencing both vibration characteristics and levels, it is difficult to quantify these relationships. Extensive use is often made of simple scaling parameters. Typical parameters used are store density, mass, surface area, skin thickness and radius. Experience indicates that such parameters can be reasonably effective when used to indicate trends in vibration severities. Three examples are presented in Figures A6 to A8. However, the application of such parameters is limited, because a single parameter cannot describe effectively vibration severities for all stores, or for the entire relevant frequency range. For this reason such parameters should be used with care.

A.4 Location

A.4.1 The thicker boundary layer towards the rear of a store and the associated higher unsteady pressures usually result in increased vibration severities in that region. These higher severities effect almost the entire frequency range of interest. In addition it is probable that detached flow will occur in the aft region. Such flow will result in even higher severities than would be expected from attached flow alone. When detached flow is extensive it may couple well with particular store modes and produce a very significant increase in amplitude over a relatively narrow frequency band. Variations of 8 to 1 have been noted in the overall vibration severity from the rear to the front of a store. For specific store vibration modes the increase may be even greater. Typical variations in responses due to store location are shown in Figure A9.

A.5 Axis

A.5.1 For store structural locations, the shape of the store external surface, the distribution of the unsteady pressure field and the store structural dynamic characteristics all contribute toward a trend which produces lower vibration severities in the axial (longitudinal) axis. This trend applies to the total frequency range of interest. Typically severities in the longitudinal axis are one half to one quarter of those in the vertical or lateral axes. Variations in response amplitude between the vertical and lateral axes are usually small. Typical effects of axis are shown in Figure A10.

A.6 Aircraft Type

A.6.1 The carriage aircraft type has only a relatively small effect on store vibration levels, and is illustrated in Figure A11 which shows the equivalent responses for the same store on different aircraft. The variations are restricted to the low frequency region, ie: below 200 Hz. At higher frequencies the effects of aircraft type are negligible; an exception being the effects of detached flow such as vortices shed from the aircraft. When the carriage aircraft configuration significantly disrupts the airflow over the store, such as for conformally carried stores, significant changes to vibration responses may be expected to occur.

A.7 Aircraft Station

A.7.1 The effects of mounting stores at different stations on the carriage aircraft usually produces only a marginal change of vibration level. The effects are restricted to the low frequencies, in a manner similar to that of aircraft type, but usually to a lesser extent. There may be exceptions when another source of excitation such as jet noise or aircraft detached flow occurs.

A.8 Store Mounting

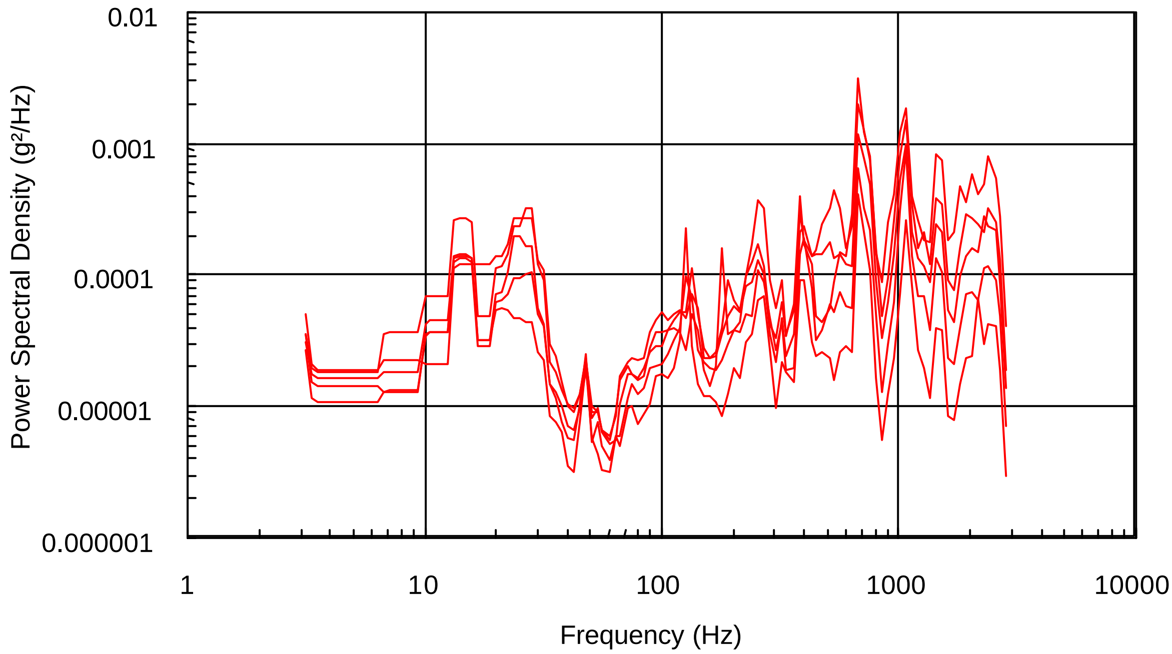
A.8.1 Again whilst the type of store mounting (ERU, MACE etc) has some effect, it is usually very small and limited to the low frequency region.

A.9 Multiple Carriers

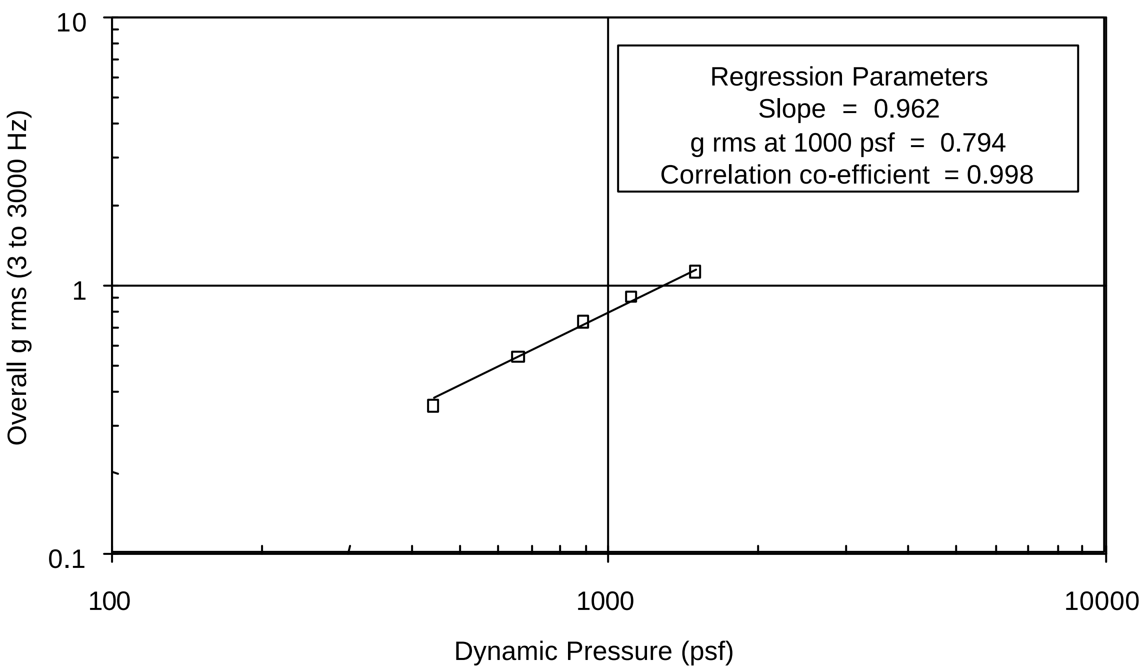
A.9.1 The use of multiple carriers has been shown to increase vibration severity. However, this appears to be a consequence of the close proximity of the carried stores restricting aerodynamic flow, see paragraph. A.10 below, rather than a characteristic of the carrier itself.

A.10 Adjacent Stores

A.10.1 Some carriage configurations place stores in very close proximity to each other. In these cases the aerodynamic flow can be modified resulting in significantly increased store vibration responses. Increases in overall vibration severity of 2 to 3 have been noted, in conjunction with very large increases (200 plus) at specific frequencies.



a. Vibration responses from five different flight dynamic pressures



b. Vibration severity (Overall g rms) versus flight dynamic pressure

Figure A1 - Relationship between store vibration and flight dynamic pressure

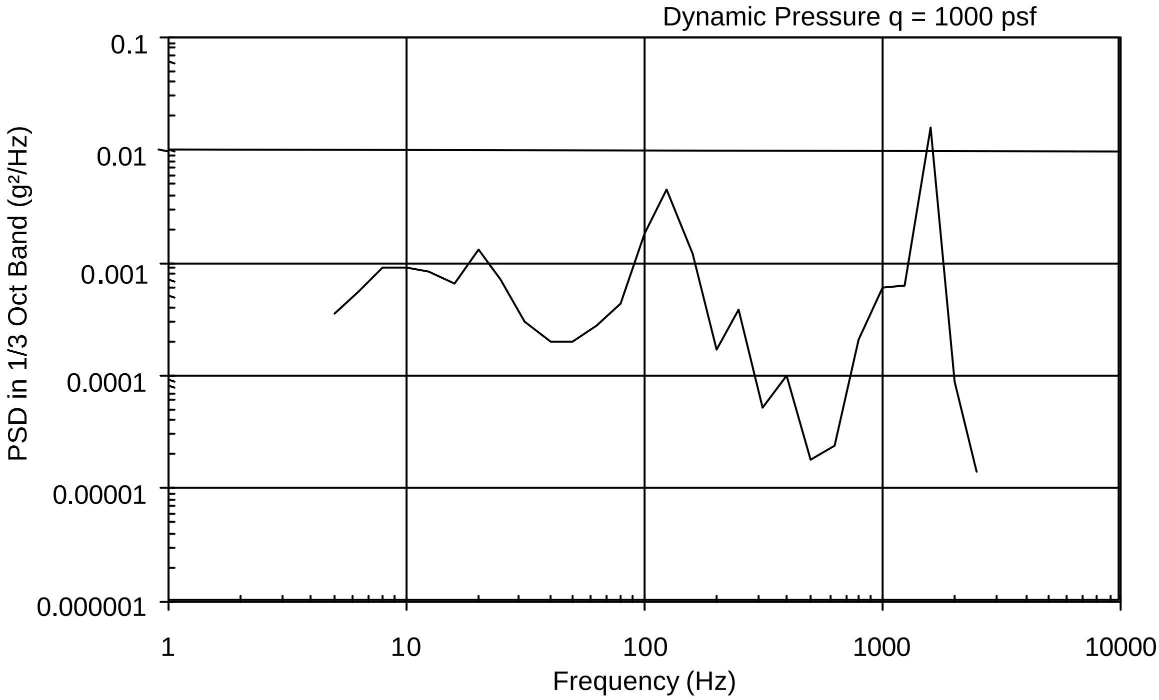


Figure A2 - Vibration response of a medium size thick skin thickness store

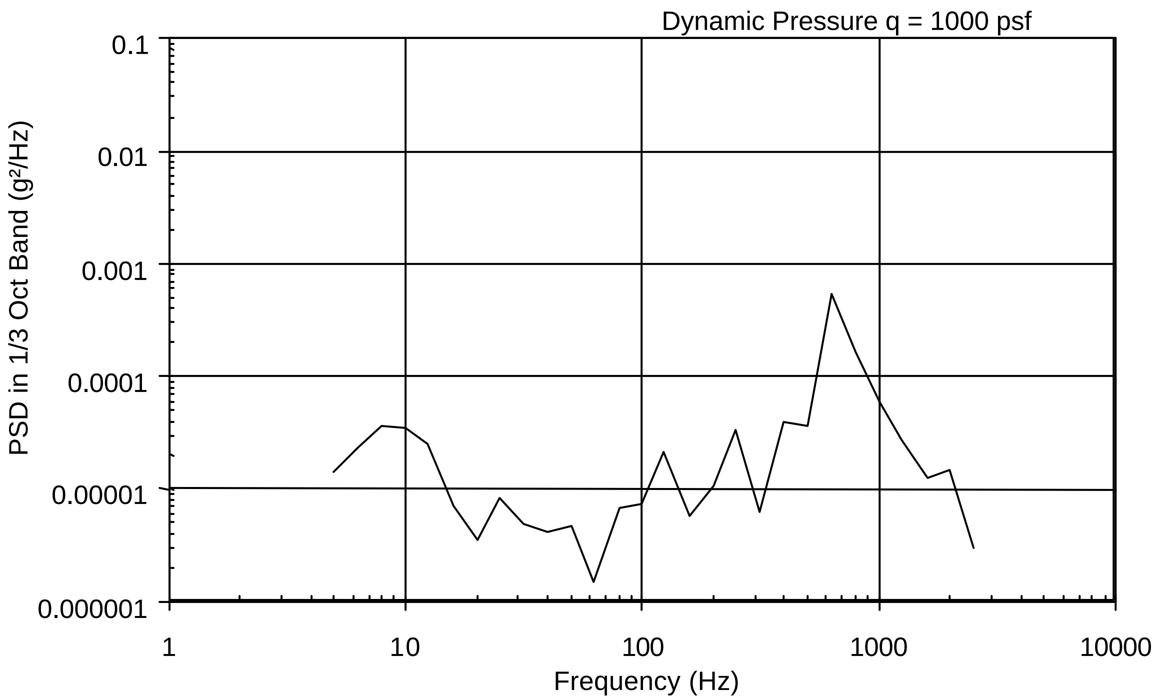


Figure A3 - Vibration response of a medium size medium skin thickness store

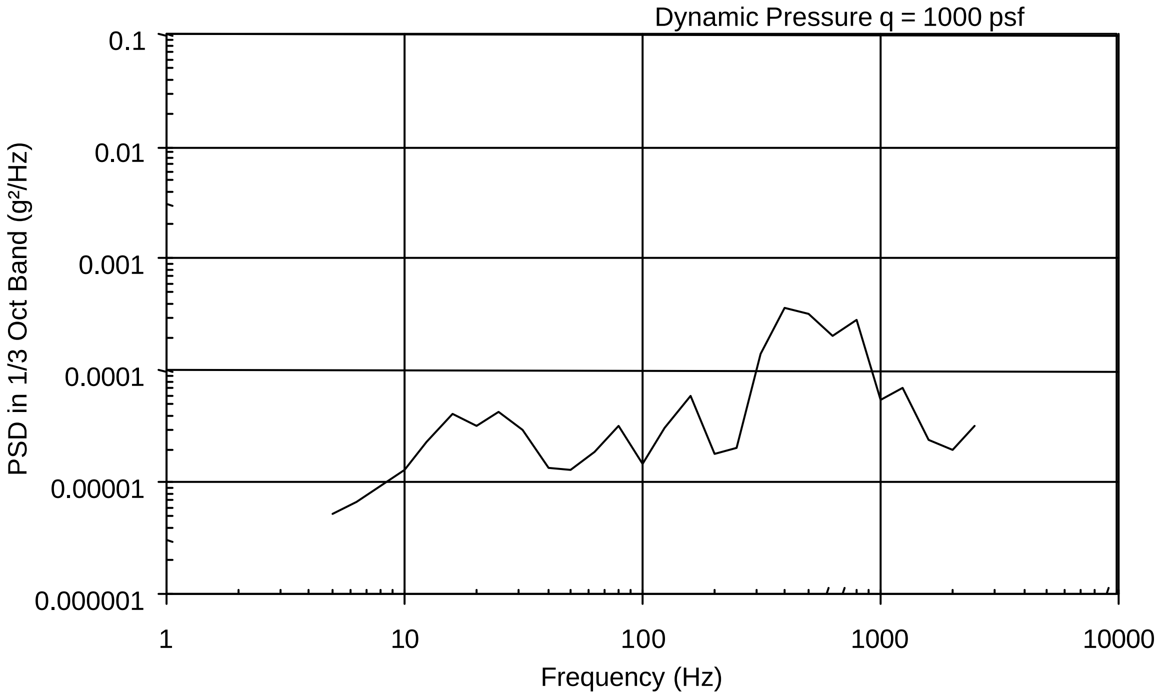


Figure A4 - Vibration response of a medium size medium skin thickness store

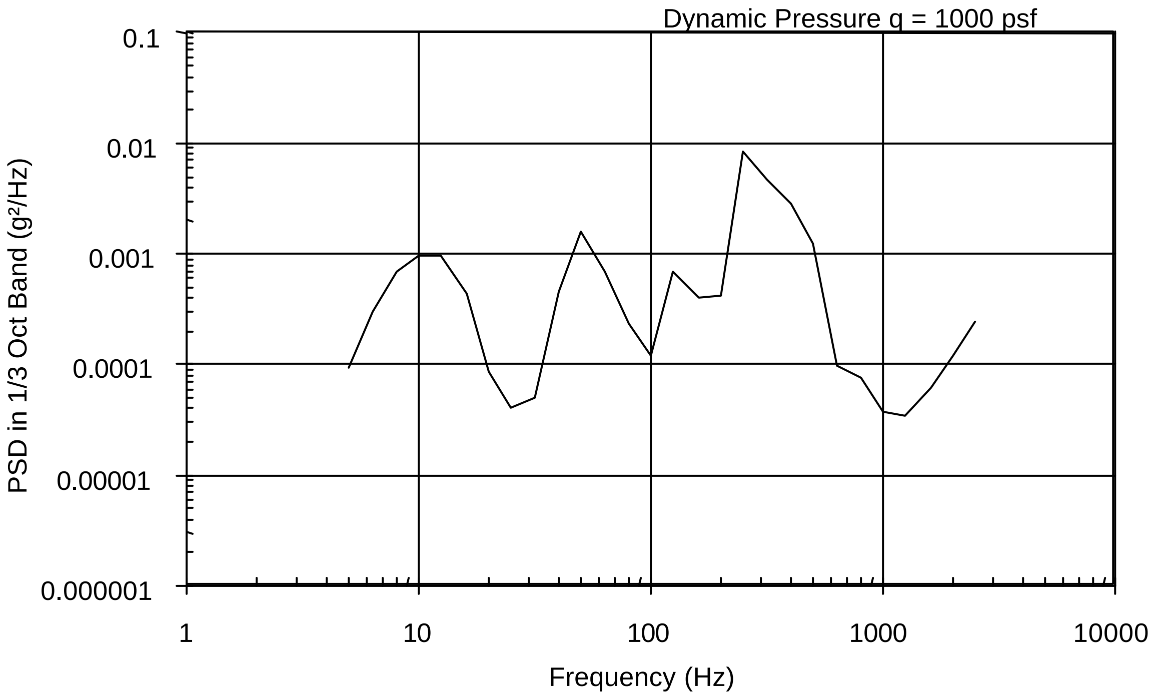


Figure A5 - Vibration response of a large size thin skin thickness store

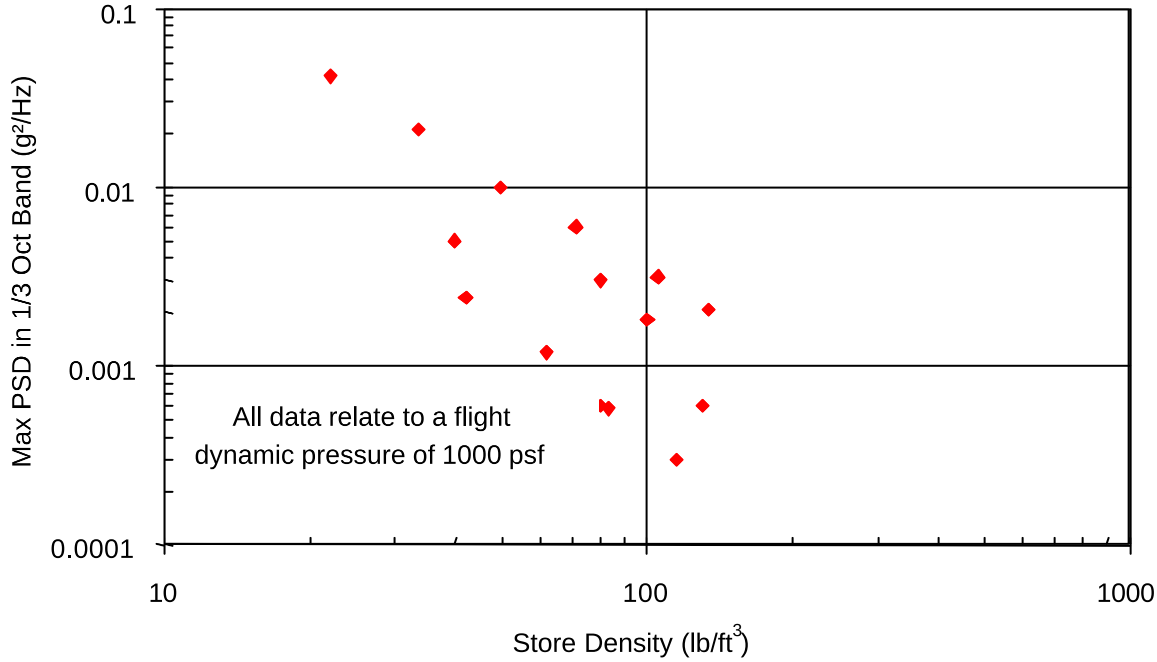


Figure A6 - Relationship between store density and maximum psd response amplitude

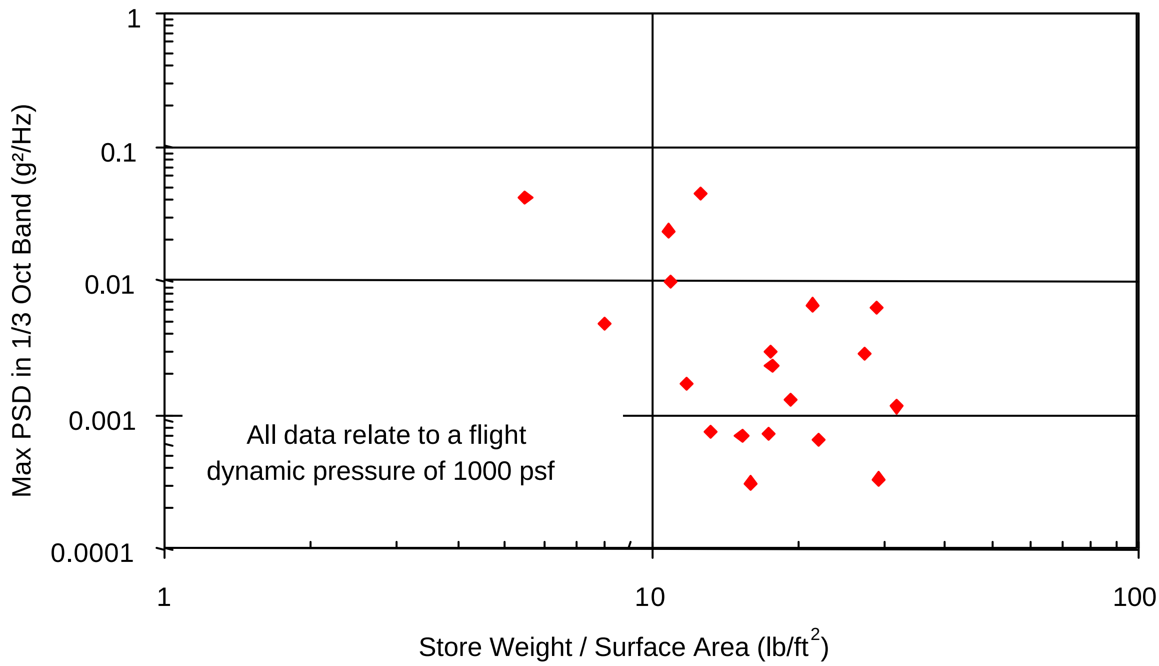


Figure A7 - Relationship between the ratio of store weight to surface area and maximum psd response amplitude

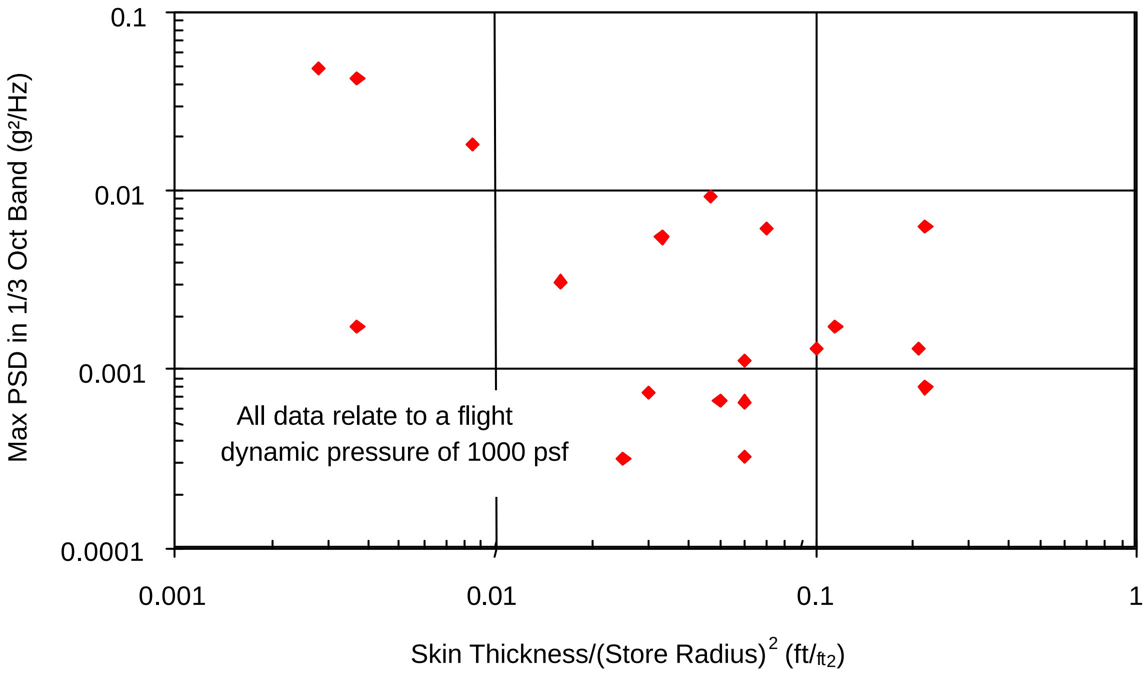


Figure A8 - Relationship between the ratio of skin thickness to store radius and maximum psd response amplitude

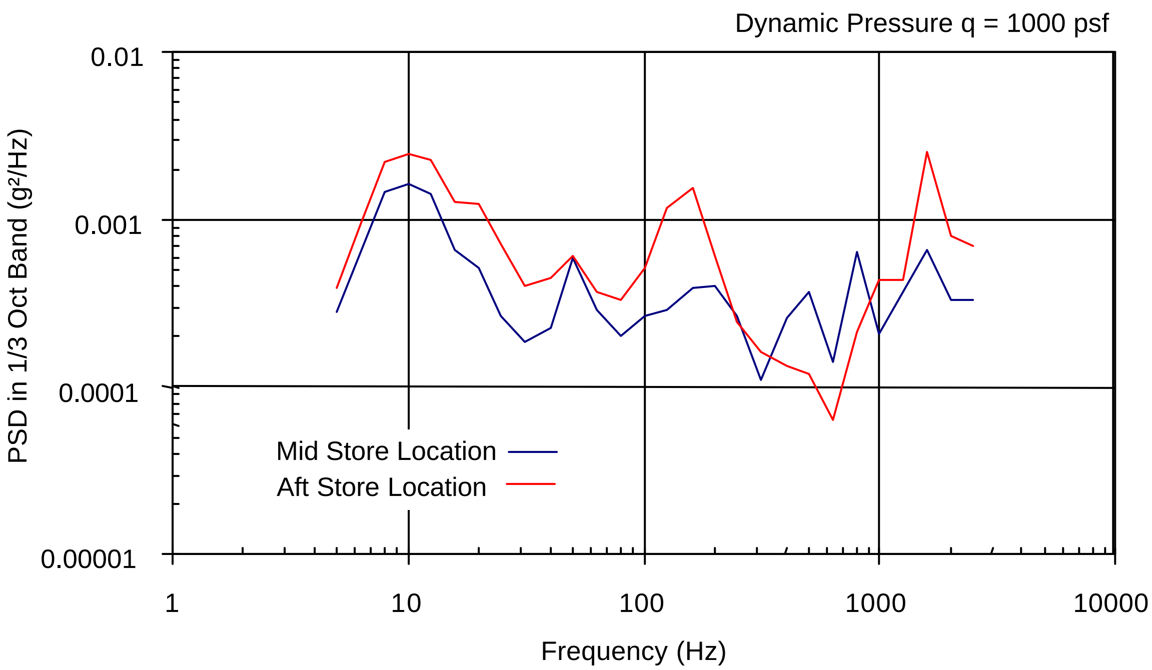


Figure A9 - Variations in vibration response attributed to measurement location

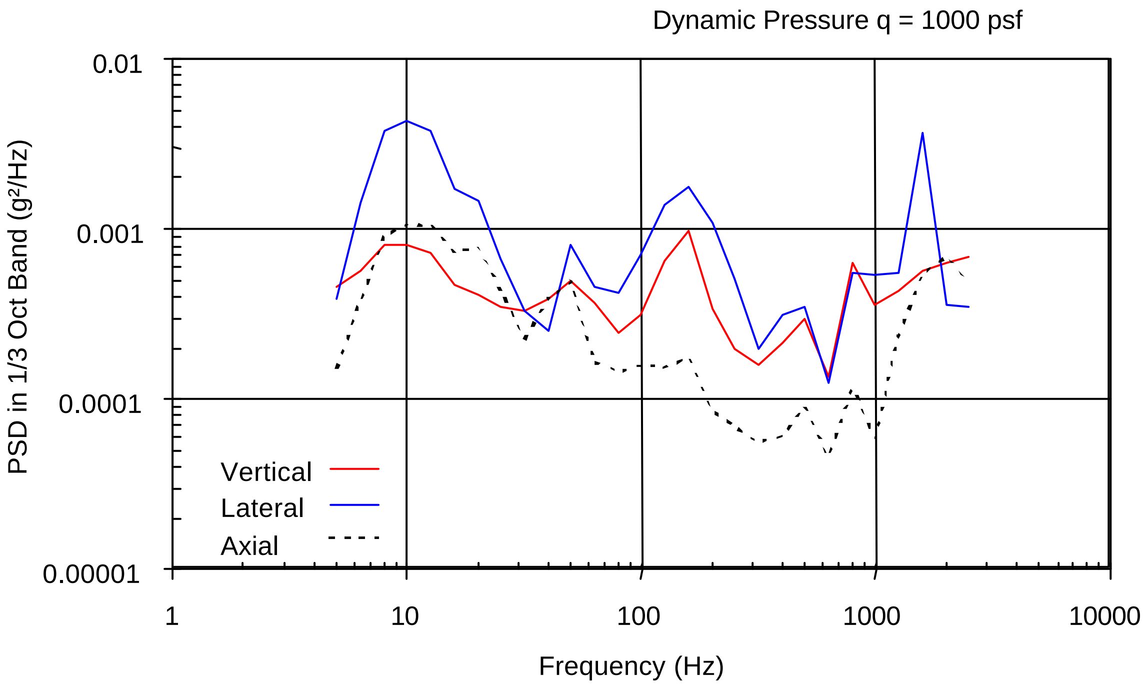


Figure A10 - Variations in vibration response attributed to measurement axis

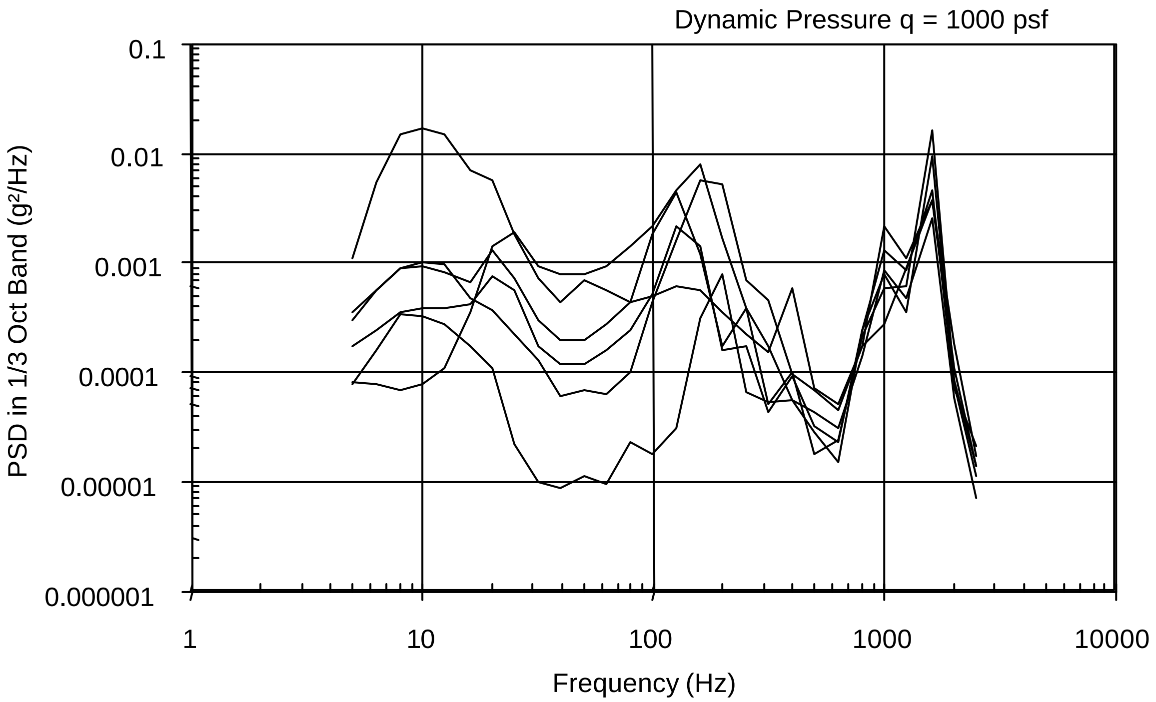


Figure A11 - Variations in vibration response attributed to aircraft type

SUB-SECTION 6/3 - DEPLOYMENT ON PROPELLER AIRCRAFT

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be experienced by materiel when deployed on, or installed in, fixed wing propeller aircraft. The sources and characteristics of the mechanical environments are discussed and when applicable, information is given on potential damaging effects. Guidance is contained in Annex A on propeller and engine vibration sources and in Annex B on the parameters influencing propeller and engine vibration.

1.2 The sub-section encompasses both internal equipment as well as external items such as stores. However, the following aspects are not included in this sub-section:

a. Materiel installed on helicopters: For information on this subject refer to Sub-section 7/1.

b. Engines and associated equipment, ie: the environments experienced by an engine and its associated equipment arising from their own operation. For information on these induced environments, reference should be made to the engine manufacturer.

c. Airframe and other primary structure: For information on loads and severities related to these structures, reference should be made to the aircraft manufacturer.

d. Abnormal conditions, such as crash and blast.

1.3 Unless specified otherwise the environmental descriptions relate to the interface between the equipment and the aircraft. Also, all axes relate to aircraft axes, with the positive longitudinal axes of the right handed axes set coinciding with the direction of normal flight (ie: forward).

2. AIRFIELD MOVEMENTS

2.1 Materiel can be expected to experience vibration and transient responses as a consequence of the aircraft movements about the airfield. Such responses are caused by the wheels traversing the inevitable irregularities in the taxi way surfaces. The severity of vibrations and transients will be influenced principally by aircraft speed and size of the aircraft wheels. The responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft.

2.2 As airfield surfaces are usually of good quality and aircraft movements are usually controlled, the severities resulting from airfield movements are usually low and significantly less than those for flight carriage. However, this may not be the case when temporary or repaired taxi-ways are used. In such cases it can be expected that a significant increase in the severity of the transients will occur. However, these conditions are unlikely to be more than those occurring during take-off and landing on repaired and temporary runways.

2.3 During ground running and airfield movements the noise and vibration arising from the engine and propeller can become significant. The mechanisms causing such effects are addressed in paragraph 4.

2.4 The motions arising from aircraft movements will result in low amplitude, high frequency of occurrence continuous responses which could cause damage through fretting fatigue mechanisms.

3. TAKE-OFF AND LANDING

3.1 Normal Take-off and Landing Conditions: During take-off and landing short duration oscillatory transients may be induced in the installed materiel. These transients arise mainly as a result of the aircraft traversing runway surface irregularities at speed. Again, the responses are dominated by the low frequencies associated with the compliance of the undercarriage and the mass of the aircraft. As both take-off and landing are usually controlled, the amplitudes of the resultant transients are usually benign. Consequently, the dynamic responses experienced during take-off and landing are normally considered to be encompassed within those of the flight phase. Take-off and landing usually involves high levels of engine power, which in turn may induce vibration and acoustic noise conditions. These related aspects are dealt with in paragraph 4.

3.2 Temporary or Repaired Runways: Continuous vibration and transient shock severities are likely to be more severe when temporary or repaired runways are used. The maximum permitted severity resulting from the use of such surfaces will depend upon the capabilities of the aircraft under consideration and in particular upon the ruggedness of the aircraft undercarriage. Consequently, where necessary, advice on severities should be sought from the aircraft manufacturer. However, any test procedures used to simulate these conditions are likely to be similar to those recommended for normal take-off and landing conditions.

3.3 Catapult Launch and Arrested Landing: Oscillatory transients will be induced in materiel during a catapult launch and/or arrested landing of an aircraft. In general catapult launch will show two transient events corresponding to initial load application and catapult separation from the aircraft. Both transient events having a distinct oscillatory nature, approximately sinusoidal, at a relatively low frequency determined by aircraft mass and landing gear damping characteristics. Arrested landing conditions produce only a single transient but with similar characteristics to catapult launch. At installed equipment locations the pulse amplitudes associated with catapult launch and arrested landing are relatively low, and the periods of application are relatively long. Therefore, these transients are usually treated as quasi-static conditions.

3.4 The motions arising from normal take-off and landing are largely dictated by the characteristics of the undercarriage system. Therefore, potential damaging effects are likely to be associated with high displacements at low frequencies.

4. FLIGHT OPERATION - ENGINE AND PROPELLER

4.1 The action of the propellers and engines is usually the major source of vibration for this type of aeroplane. However, vibration measured at a point in an aeroplane's fuselage will be the sum of many sources and mechanisms. Some generate vibration directly whilst others generate noise which produces vibration when it impinges on the aeroplane's structure.

4.2 Because of their diverse nature and interactions, vibration spectra can possess features which may be complicated to explain, eg: the cancelling or enhancement of certain propeller blade passing harmonics. Examples of vibration spectra obtained during cruise conditions are illustrated in Figures 1 to 4 for four different aircraft. The relative severity of vibration at propeller blade passing frequencies for these aircraft is illustrated in Figure 5.

4.3 Further information on several vibration sources arising from propeller and engine actions is given in Annex A.

4.4 The severity and character of the vibration environment experienced by a particular item of equipment installed at a specific location in a propeller aeroplane can depend on a number of parameters, such as aeroplane type, flight condition, etc. The effects of these parameters are discussed in Annex B.

4.5 Figures 1 to 4 show that the vibration environment associated with propeller aeroplanes is comprised of broad band random vibration spectrum, upon which is superimposed relatively strong forcing centred at frequencies associated with harmonics of the propeller blade passing. Vibration can also be evident, usually at relatively low levels, at frequencies associated with harmonics of propeller shaft rotation. The severity of the background random vibration is usually low. Periodic vibration at the propeller blade passing frequencies may amount to 90% of the overall g rms in a 2 to 2,000 Hz frequency bandwidth.

4.6 The frequency of the blade passing periodic component of the vibration responses usually occurs in the range 50-100 Hz. This range will coincide with the first mode of vibration of many items of equipment, especially those on flexible mounts. As such the periodic excitations may result in significant velocity and displacements occurring, which in turn may result in damage particularly to lightly damped equipments.

5. FLIGHT OPERATION - AERODYNAMIC FLOW

5.1 Another significant source of propeller aircraft equipment vibration is associated with the turbulence in the airflow surrounding the aeroplane. This airflow over the structure may be smoothly attached to it, or it may be detached. These two conditions produce significantly different vibration excitations. The more severe vibration conditions are associated with detached flow which exists on all aeroplanes. Vibration arising from aerodynamic flow is presented in Sub-section 6/1 paragraph 4.

5.2 As the vibrations arising from aerodynamic turbulence are broad band random, the potential damaging effects are typical of those from this class of excitation eg: brinelling, fretting, high cycle fatigue etc. Detached flow can result in a significant increase in efficiency by which particular modes are excited. As a result the amplitude of response of certain modes can increase by several orders of magnitude which may lead to rapid structural failure due to fatigue.

6. FLIGHT OPERATION - VORTEX IMPINGEMENT

6.1 At certain conditions of angle of attack, heading and airspeed it is possible for vortices originating from parts of the aeroplane to impinge on downstream structure. The characteristics of these vortices is such that severe structural vibrations may arise at the downstream structure. In general these vibrations may be dominated by the lower structural modes of the particular portion of the airframe (wing, empennage etc). These vibratory conditions are transitory in nature and rarely occur for more than a few seconds at any one time. However, during the life of an aeroplane the total number of such occurrences may be significant. The resulting vibration characteristics, severity and areas of airframe significantly effected will be unique to a specific aircraft type.

6.2 The vibrations arising in structure under the leading edge of a vortex appear almost periodic in nature. The severity can be high but relatively localised. The vibrations may rapidly result in acoustic fatigue of panels and, in some cases, of nearby equipment. The vibrations arising down stream of a vortex are considerably more significant and can induce high amplitude vibrations at lower frequency modes of the structure. In some cases the accrued fatigue damage may be equal or greater than the accrued damage from normal flight manoeuvres.

7. CAVITIES

7.1 Cavities exposed to a grazing flow as it passes the aeroplane can be a significant source of both noise and vibration. The frequency spectrum of such disturbances can be wide in range and usually features sharp peaks and troughs over the frequency range. The main peaks arise from the excitation of acoustic “space” modes which are a direct function of the dimensions of the cavity. A weapon or bomb bay is an obvious example of such a cavity. The frequencies of the main modes can be calculated with some confidence from standard formulae. The majority of the less dominant modes are usually harmonics of the main modes and can persist up to quite high orders. The amplitudes of the pressure fluctuations are less easily estimated because they are affected by geometrical factors such as the sharpness of the edges of the cavity, the direction of flow over the cavity and the contents of the cavity. The contents of the cavity can have the effect of making the main modal peaks less discernible whilst increasing the level of the background broad-band “noise” which is always present.

7.2 Acoustic waves can induce failure of panels within a cavity very rapidly. In addition high levels of vibration may be induced in equipment within the cavity.

8. MANOEUVRES AND GUST

8.1 Equipment will experience low frequency acceleration loadings due to flight manoeuvres and gusts. These are normally considered as quasi-static loadings for design and test purposes. At a particular aircraft location the loadings arise mainly from the vector sum of the six “rigid body” aircraft degrees motions ie: vertical, lateral, longitudinal, roll, pitch and yaw. These may be amplified by the dynamic motions of the lower aircraft modes.

8.2 The severity of the flight acceleration environment will depend mainly upon the type of aircraft under consideration. Generally the flight accelerations are a specified design requirement for a particular aircraft type and hence are well defined early in a design. These accelerations are usually constrained by flight limitations procedures or the control system computers. Many aircraft contain equipment which monitor these loadings for fatigue purposes.

9. GUNFIRE

9.1 Significant vibration and shock excitations in aeroplane structure, equipment and stores can arise from the operation of guns installed either within the aeroplane or in external pods. Whilst the total duration of these excitations is relatively short the amplitudes can be several orders of magnitude greater than the vibrations arising during normal flight. Moreover, the characteristics of the responses, for some equipment and structure, can be significantly different to the vibrations occurring during normal flight conditions, and may induce different equipment failure modes. Details of the mechanisms causing dynamic mechanical responses as a result of gunfire are presented in Sub-section 6/1.

9.2 In the near field the blast pressure wave is sufficient to cause structural failure of panels and their supports. Equipment in close proximity to the muzzle, but protected from the direct blast pressure wave, may fail due to the severity of the repetitive but discrete shock pulses t experiences. The most likely failure modes of equipment in the middle field are those associated with high intensity, low frequency vibration.

10. LAUNCH OF WEAPONS

10.1 The launch or firing of weapons can, in certain circumstances, induce high level of shock, vibration and pressure blast in the aircraft structure, nearby weapons or stores.

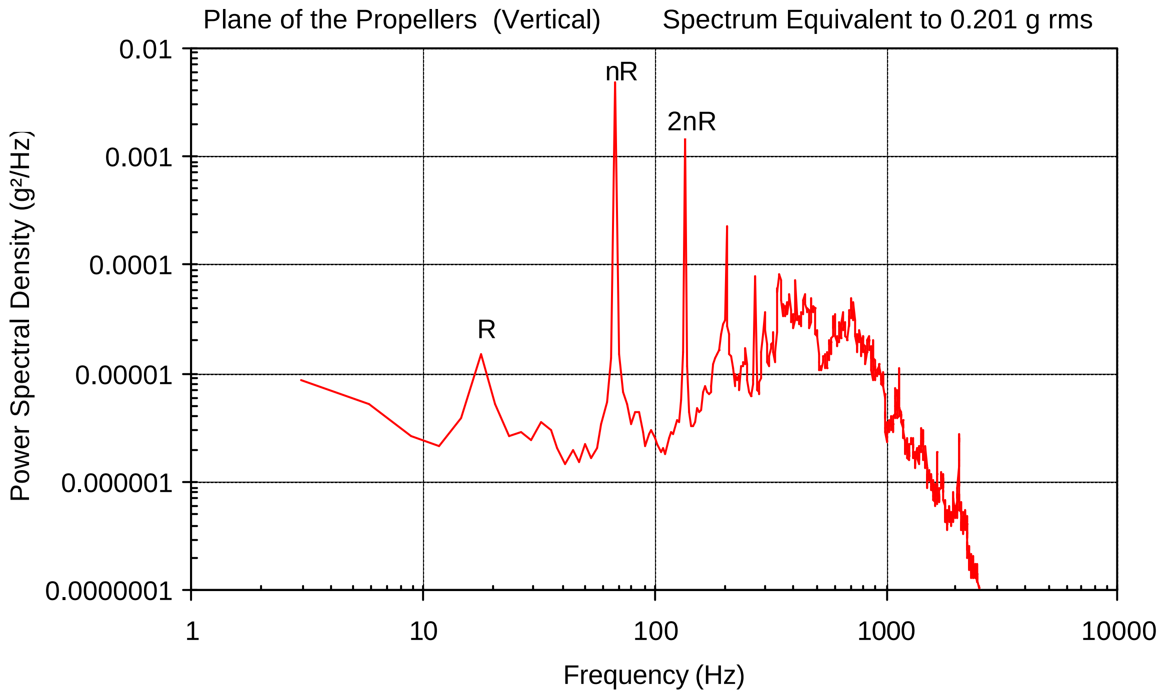


Figure 1 - Vibration spectrum from a C130 Hercules Mk1 during cruise

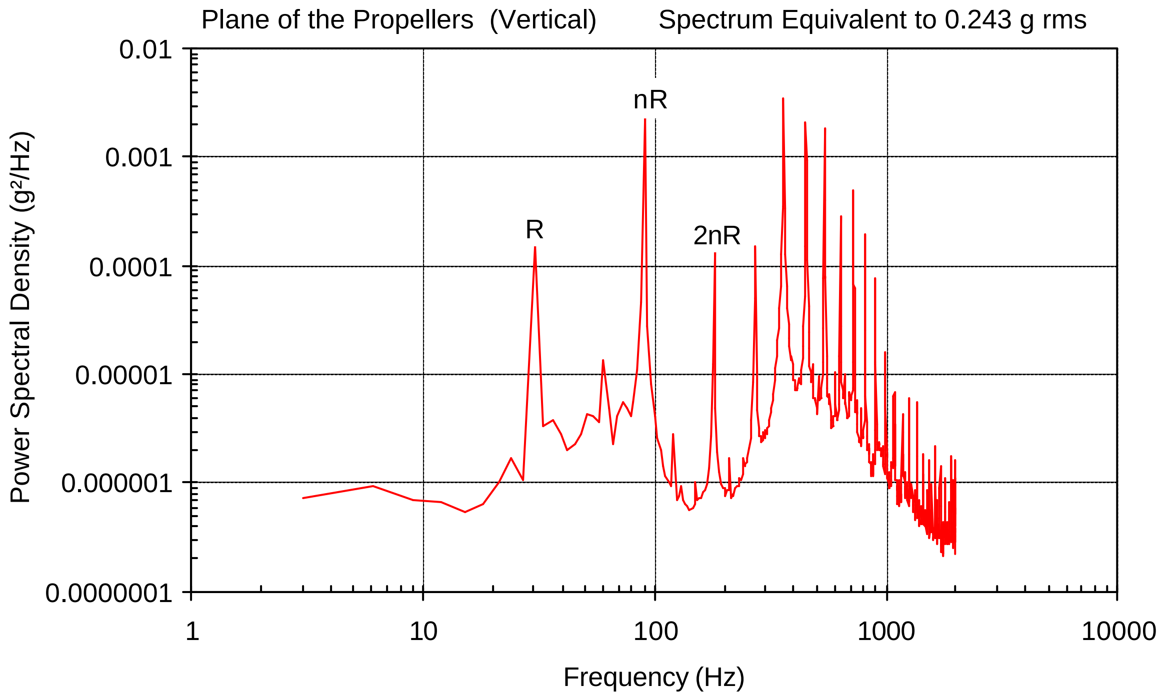


Figure 2 - Vibration spectrum from a Jetstream Mk1 during cruise

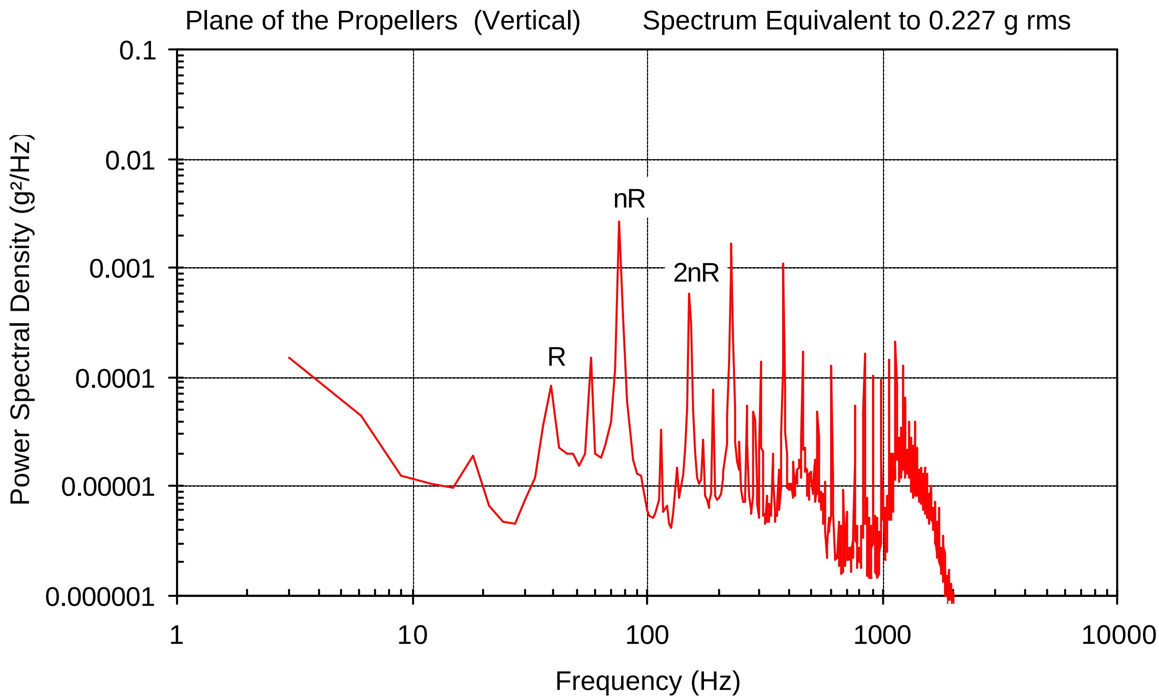


Figure 3 - Vibration spectrum from an Islander during cruise

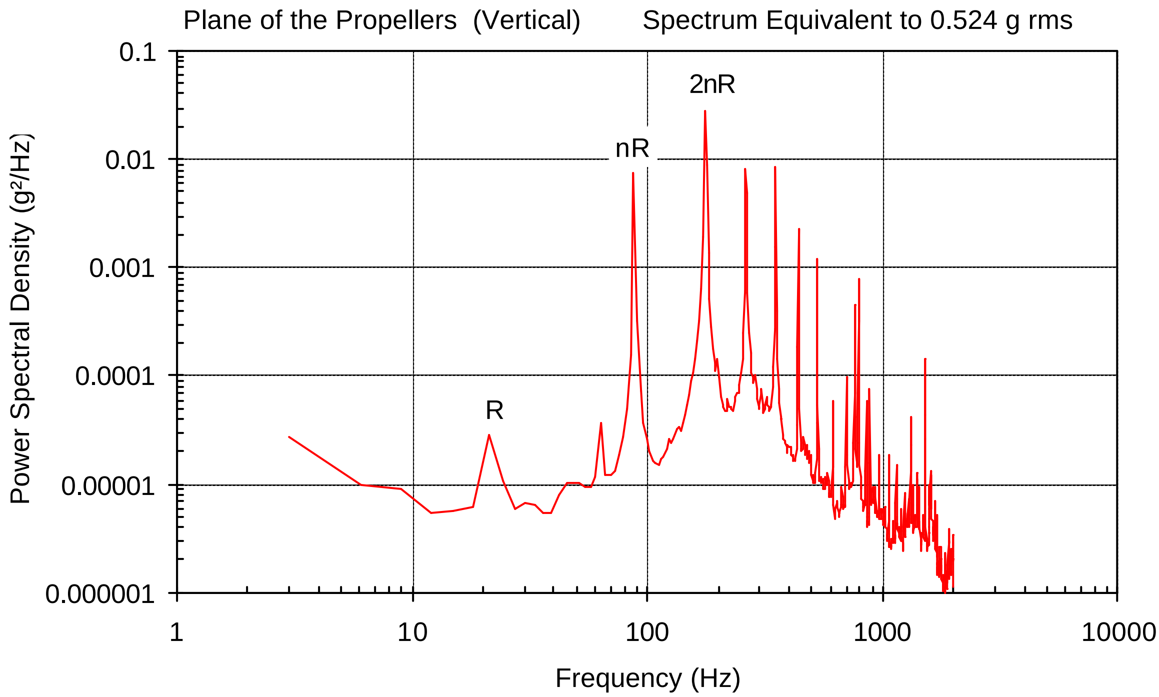


Figure 4 - Vibration spectrum from a BAe 748 during cruise

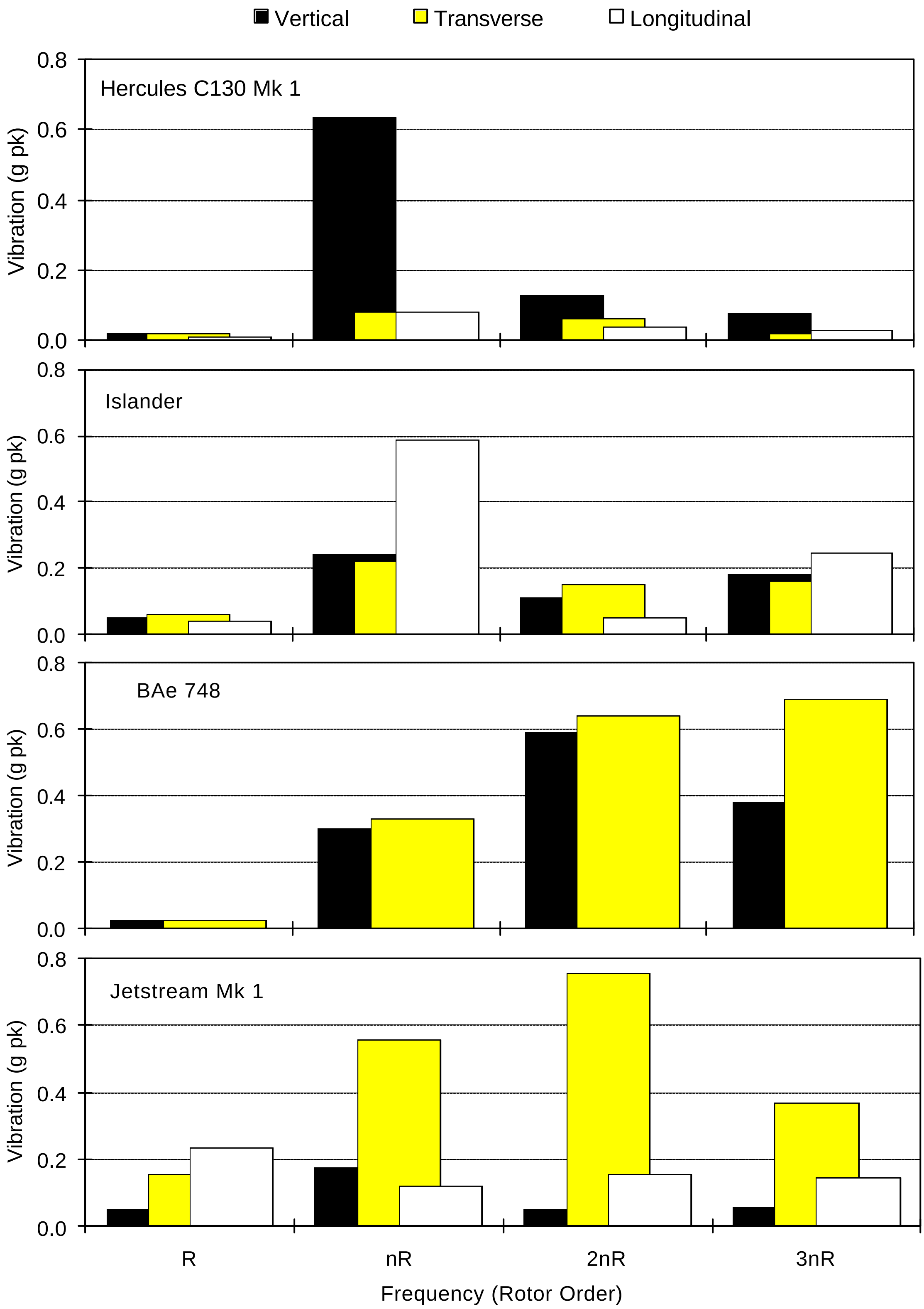


Figure 5 - Vibration at rotor orders for four propeller aircraft for cruise

PROPELLER AND ENGINE VIBRATION SOURCES

A.1 Mechanical Imbalance.

A.1.1 Vibration is caused by mechanical imbalance of a propeller and will be apparent at the shaft rotation frequency and subsequent harmonics. Imbalance can arise through the natural action of erosion over a period of time. Routine aeroplane maintenance should minimise this vibration, but some residual imbalance is likely as it can be difficult to dynamically balance a variable pitch propeller.

A.2 Propeller Blade Modes.

A.2.1 Propeller blade modes can be excited by forcing functions such as the air moving through the propeller disc or by blade-wing interactions (see below), and this can cause vibration to be transmitted through the propeller's hub bearing and into the aeroplane's structure. This is unlikely to be a major source of vibration as designers will attempt to minimise blade vibration to prolong the life of the propeller.

A.3 Airflow Interference.

A.3.1 Vibration can be induced into the propeller blades, and transmitted to the aeroplane's structure via the propeller hub bearing, by the air flow streaming back from the propeller meeting an impedance caused by the presence of the wing and its surrounding pressure field. This vibration occurs at a characteristic frequency dependent on the number of interferences per revolution of the blade and the blade passing frequency. Some harmonics may be missing in measured spectra because the resultant force acting on the blades is the vector sum of the forces acting on the whole propeller, ie: some harmonics may add and others subtract. The significance of this source, which is only applicable when the propeller is in front of the wing, is dependent upon the propeller to wing dimension. The worst type of propeller with respect to blade-wing interaction effects is a two bladed type.

A.4 Propeller Pressure Fields.

A.4.1 Excitations arising from propeller rotation can be conveniently considered in two different regimes, that is with the blades developing thrust and at zero thrust. In the latter case flow noise is produced which is usually referred to as thickness noise. In the former condition thickness noise is still produced but this may be augmented by another form of flow noise referred to as rotation or force noise.

a. Thickness Noise: In the zero thrust case, noise is generated as a consequence of the finite thickness of the propeller blades. This noise is generated by air moving out of the way of an advancing blade and then returning after the blade has passed. The resulting pulsation of air acts as a classic noise source. When considering this mechanism the propeller disc is seen to consist of a set of pulsating sources with appropriate phase relationships. At the fuselage, this is perceived as a series of broad band pulses arriving at the blade passing frequency.

b. Rotation or Force Noise: When a blade develops thrust additional flow noise may be generated as a result of blade encountering disturbed airflow, in particular vortices originating from the preceding blade. Usually thickness noise dominates whether rotation or force noise is present or not. However, under certain conditions this may not necessarily be the case. The rotation noise produced by a blade developing thrust cannot be calculated as accurately as that for just thickness noise. This is due in part to the complicated nature of the velocity field of the airflow past the propeller disc. The many approaches that have been used to consider this mechanism have all had to assume some approximated pressure distribution over a blade and to transfer these total pressures to the equivalent fixed force acting around the propeller disc. As for thickness noise the noise source is identified as acoustic dipoles and the total acoustic power is derived by integrating over the propeller disk.

A.5 Vortices.

A.5.1 Vortices are shed from the tips of rotating propeller blades. This mechanism produces a broad band noise spectrum which is likely to peak at a frequency (f) associated with the Strouhal Number, ie:

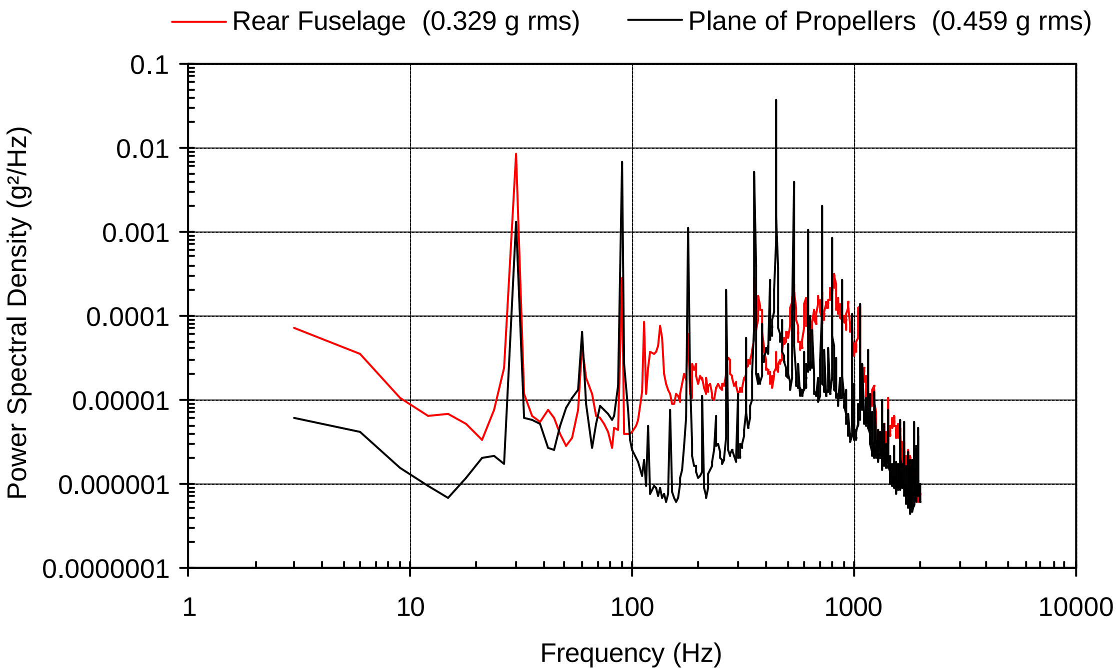
$$f = K V / d$$

where V = the rotational velocity of the blade tip
d = a dimension which typifies a blade chord
K = a constant

Vibration effects arising from vortices would not be expected to be significant for an aeroplane that has a pusher propeller because of the directivity characteristic of vortex noise.

A.6 Directivity Effects.

A.6.1 The sources of vibration, detailed above, are each characterised by a particular directivity pattern. Propeller rotation noise is at a maximum in the plane of the propellers. Mechanical and aerodynamic imbalances also tend be most significant close to the plane of the propellers. Effects of vortices shed from the tips of the propellers will be most apparent towards the rear of the aeroplane. Blade thickness noise also tends to radiate most strongly to the rear of the plane of the propellers. Figure A1, which shows aeroplane structural vibration spectra from positions at the plane of the propellers and at the rear fuselage of a Jetstream Mk 1 aeroplane, illustrates the effects of the directivity and the nature of the various sources discussed above It can be seen from this figure that periodic vibration, particularly at the blade passing frequency and its harmonics, is most severe in the plane of the propellers, and that broad band vibration in the 500 to 1200 Hz range is most severe at the rear of the aeroplane.



Note: Data taken at 215 kns straight and level flight

Figure A1 - Comparison of spectra from forward and rear location in a Jetstream Mk1 aircraft

PARAMETERS INFLUENCING PROPELLER AND ENGINE VIBRATION

B.1 Aircraft Type

B.1.1 Different aircraft can be expected to have different engine operating speeds, and to have different numbers of propeller blades, leading to different blade passing frequencies, as illustrated in Figures 1 to 4. As result, it cannot be expected that vibration data relating to one particular propeller aircraft is applicable to another. This is somewhat different to the case of jet aeroplanes, where a prime parameter governing vibration severity is flight dynamic pressure, ie: aeroplane speed. For propeller aircraft, parameters associated with the aircraft itself, rather than its speed or the air through which the aircraft travels, most significantly affect vibration severity. Some current propeller aircraft have fixed speed engines, ie: the engines are governed to within a few per cent of their nominal speed. For these types of aircraft, power demand is achieved by the use of variable pitch propeller blades. Some aircraft, however, have fixed pitch propellers but variable speed engines, eg: reciprocating engines, although in these cases there are usually recommended engine speeds for particular manoeuvres, eg: take-off or cruise. Other aircraft may generate the required power demand by varying both engine speed and propeller pitch. Clearly, equipment installed in an aircraft with a variable speed engine would be expected to experience excitation over a wider frequency range than its fixed engine speed counterpart. Blade passing frequencies are usually in the range of 60 to 100 Hz. This results from a number of physical constraints, eg: the propeller diameter, and the need to maintain efficiency by avoiding supersonic blade tip speeds.

B.2 Flight Condition

B.2.1 For propeller and most other forms of aircraft, maximum vibration usually occurs during periods of maximum power demand such as during take-off. Take-off is however a short duration event, eg: 25 s. Climb can also produce relatively high levels of vibration. Cruise is less severe in terms of amplitude, and descent more so. Vibration severity associated with landing can be as severe as take-off if reverse thrust is applied, although the duration of this is likely to be even less than that of take-off, eg: 10 s. Whilst the severity of cruise is usually relatively low, the blade passing frequency associated with this condition could nevertheless be critical for particular equipment. Furthermore, cruise can be most significant in terms of structural fatigue because of the long durations associated with this flight condition. The relative severity of a variety of flight conditions is illustrated in Figure B1 in terms of the overall acceleration rms (2 to 2000 Hz) measured on an aircraft's structure. It can be deduced from this figure that vibration severity is dependent on power demand. This deduction is broadly confirmed by the graphs of vibration versus power demand presented in Figure B2 for a Jetstream Mk 1 aircraft.

B.3 Position in the Aircraft

B.3.1 Vibration severity is dependent upon the distance from the plane of the propellers, where vibration severity is usually at a maximum. A diagram showing how vibration severity varies along the length of a Jetstream Mk 1 aircraft is presented in Figure B3. It can be seen that in this particular aircraft, vibration in the dominant lateral axis at the rear of the aircraft is only around 25% of that in the plane of the propellers. Spectra relating to positions in the plane of the propellers and at the rear of a Jetstream Mk 1 aircraft are compared in Figure A1. From this figure it can be seen that whilst the severity at frequencies related to propeller blade passing is lower at the rear position, the severity of the broad band vibration is greater at the rear than in the plane of the propellers. This broad band vibration is likely to be associated with vortex shedding and blade thickness noise.

B.4 Materiel mounting

B.4.1 Materiel mounting arrangements can influence its vibration response. Clearly it is desirable that designers ensure that frequencies associated with the materiel do not coincide with propeller shaft rotation or blade passing frequencies associated with the host aircraft. Whilst this may not be possible if the engine is a variable speed type, at least the dominant frequencies which are present for the majority of the time, eg: during cruise, should be avoided. In practice, this can be difficult because of the number of significant blade passing harmonics, as illustrated in Figures 1 to 4 of this sub-section. Potential problem areas are associated with the materiel's installed natural frequency (dependant upon the materiel's mass and the stiffness of its mounts) and resonances within the materiel (eg: flexing of printed circuit boards).

B.5 Materiel Alignment

B.5.1 Considerable variations have been seen in the relative severity of three vibration measurement axes, depending on aircraft type. Whilst the most severe vibration tends to occur in either the vertical or transverse axis, relatively high levels have been observed in the longitudinal axis, as illustrated in Figure 5 of this sub-section. This suggests that if flight measurements are being made, all three axes should be included.

B.6 Other parameters

B.6.1 Differences in the vibration severity of nominally identical propeller aircraft have been attributed to indeterminable structural differences. For example, in a survey comprising twelve flights on C130 (Hercules) aircraft, involving different airframes, the coefficient of variation (standard deviation divided by the mean value) was around 30% for the dominant frequency components. Such variations in severity need to be taken into account when compiling environment descriptions or test specifications.

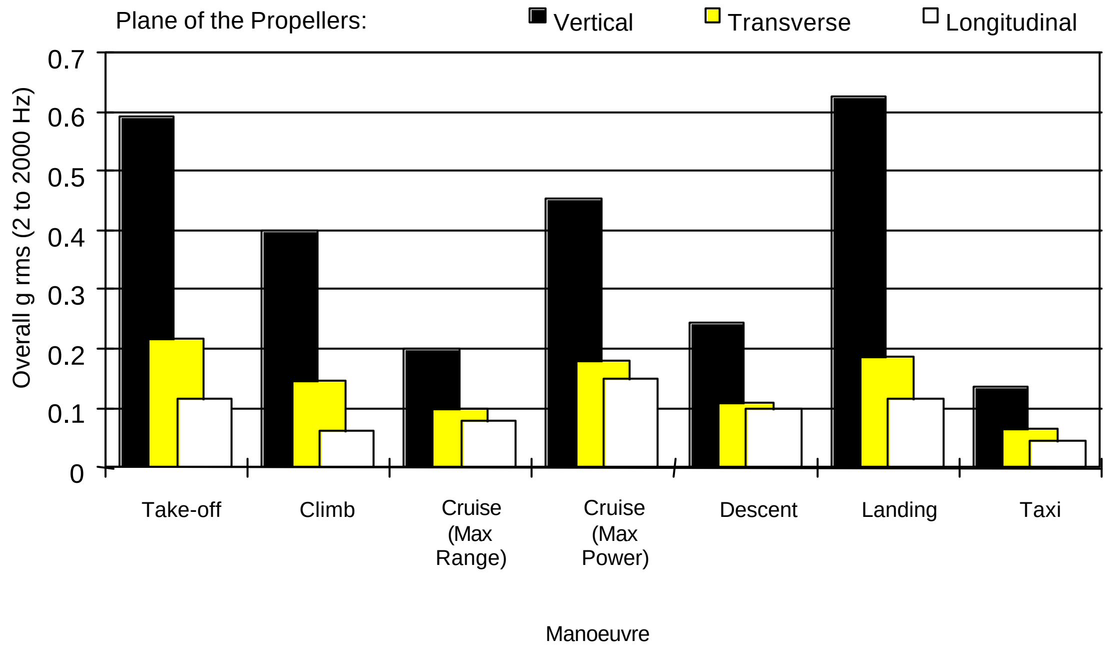


Figure B1 - Examples of Hercules C130 Mk1 vibration severity for various flight conditions

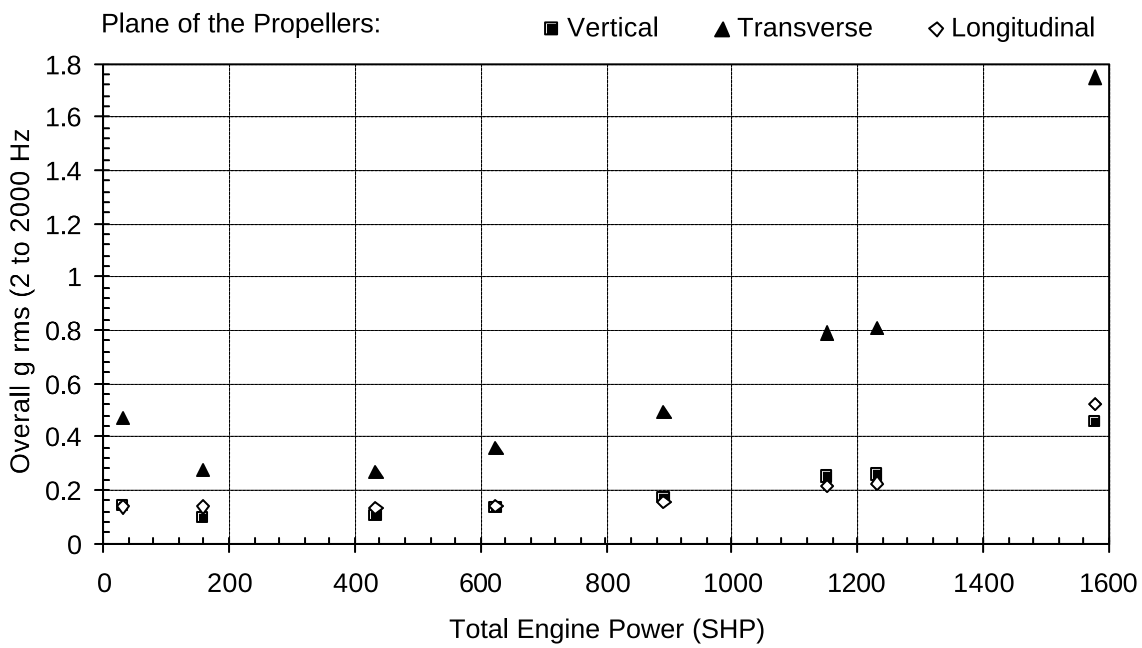


Figure B2 - Vibration severity versus power demand for a Jetstream Mk1 Aircraft

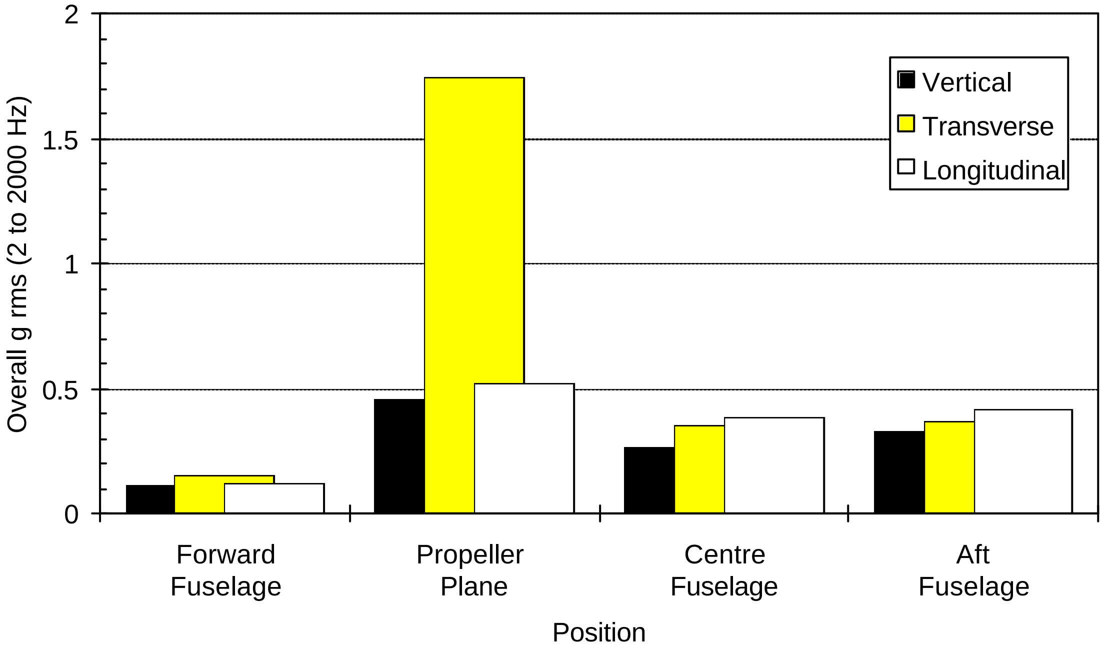


Figure B3 - Variation of vibration severity along the fuselage of a Jetstream Mk1 aircraft in cruise

SECTION 7

DEPLOYMENT ON ROTARY WING AIRCRAFT

SUB-SECTION 7/1 - DEPLOYMENT ON ROTARY WING AIRCRAFT

1. GENERAL

1.1 This sub-section addresses the mechanical environments encountered by materiel when deployed on or installed in rotary wing aircraft such as helicopters. The sources and characteristics of the environments are presented and where applicable, information is given on potential damaging effects. Guidance is contained in Annex A on the parameters influencing the severity of the mechanical environments.

1.2 Consideration of the sources of vibration, as presented in Annex A, suggests that it is realistic to characterise vibration spectra associated with helicopters by discrete peaks superimposed upon a background of broad band random vibration. Helicopter engine speeds are governed generally to within 2% and so the frequencies of the rotating components are similarly bounded

1.3 In the course of their missions, helicopters carry out many flight conditions, which may include hover, straight and level flight (forwards, backwards and sideways), climb, descent, turns, acceleration, deceleration, etc. For data processing purposes these conditions may need to be classified into two groups, ie: steady and non-steady state, because different techniques are appropriate for each group. The former group would include straight and level flight and other relatively steady-state conditions, while the latter group would include the transition from forward flight to hover and other relatively transient conditions.

1.4 Typical acceleration histories from a store carried externally on a Sea King helicopter during straight and level flight at maximum speed (Vne) are presented in Figure 1. This figure presents data from the vertical, transverse and longitudinal axes. Figure 2 shows a frequency analysis up to 500 Hz for the vertical axis acceleration history presented in Figure 1. In Figure 2 the excitation harmonics associated with the main rotor blade passing frequency of the Sea King can be clearly seen. A further frequency analysis of this data up to 3000 Hz is presented in Figure 3. It can be seen from Figure 3 that responses above 200 Hz are at a very low level, apart from a peak centred around 700 Hz which is attributed to gear tooth meshing.

1.5 An amplitude probability density (APD) analysis has also been carried out on this vibration record; the resulting plot is shown in Figure 4. The characteristic of the APD data is midway between that of random vibration and that associated with sinusoidal vibration.

1.6 Studies have shown that parameters which influence the vibration characteristics of helicopter equipment fall into four categories, ie: flight conditions, helicopter variations, load configuration and measurement position/axis. These parameters should be considered when compiling test specification from measured data.

2. FLIGHT CONDITIONS

2.1 Helicopter vibration usually depends on the speed of the helicopter, as illustrated in Figure 5. It should be noted from this figure that maximum vibration does not always occur at maximum speed, but can be associated with a sub-cruise speed.

2.2 The transition to hover from forward flight usually generates the most severe vibration conditions, which can exceed that of cruise by up to four times, albeit for only a few seconds. The transitory nature of this manoeuvre is illustrated by the acceleration history presented in Figure 6. Effects of take off and landing are not significantly different to those associated with the hover condition.

2.3 During flight manoeuvres and gusts the helicopter will experience acceleration loadings. For design and test purposes, these acceleration loadings are usually considered “quasi-static” in nature. Their effects can sometimes be amplified by coupling with the dynamic motions arising from the lower frequency airframe modes of vibration, although such coupling would be expected to be considered and prevented at the helicopter design stage.

2.4 A major potential problem area for materiel mounted on helicopters is possible coupling between the helicopter’ blade passing related frequencies and frequencies associated with the materiel, ie: of the materiel on its mounts or of its internal components. Not only can this coupling lead to materiel failure but excessive loads can be introduced into the helicopter’s airframe.

2.5 As a result of in-flight manoeuvres or the effect of gusts, inertial loadings can be induced within materiel and at its attachment points to the airframe. Such loadings can produce structural fatigue failures or degrade the correct functioning of mechanisms.

3. HELICOPTER VARIATIONS

3.1 Observations from cabin measurements, the vibration characteristics of which are particularly applicable to internal equipment, rank helicopters according to severity in the order of Chinook, Lynx and Sea King. However, data relating to externally carried stores on the Sea King and Lynx, indicate that Sea King is the more severe. The variation in severity, ie: best to worst, for samples of Lynx and Chinook helicopters, has been seen to be up to 5:1 for the dominant frequency components. For a given helicopter type, the variation in store vibration amplitude due to carriage station has been seen to vary by up to 3:1.

4. LOAD CONFIGURATION

4.1 The attachment of massive equipment (particularly of stores) produces installed natural frequencies of the equipment/carrier/helicopter combination. Problems of excessive vibration can occur if such frequencies coincide with any of the major forcing frequencies, such as blade passing, associated with the host helicopter. Mixed carriage loads of external equipment can also influence vibration severity, increases of 1.6 times have been observed.

5. MEASUREMENT POSITION AND AXIS

5.1 A helicopter vibration measurement will be influenced by its proximity to the various sources of excitation and also the type of structure to which the measurement transducer is attached. For external stores, where significant rigid body motions may occur, additional influences can be the position of the transducers along the store and the sensing axis.

6. GUNFIRE

6.1 Materiel responses to gunfire and associated potential damaging effects are discussed in Sub-section 6/1, Deployment on Jet Aircraft.

7. LAUNCH OF WEAPONS

7.1 This environment encompasses the launch of weapons from the host helicopter, eg: the launch of TOW missiles. The launch of weapons can subject the helicopter airframe to high levels of shock, vibration, blast pressure and rocket motor efflux. These conditions are highly specific to particular weapon/helicopter installations and therefore generalised guidance is inappropriate.

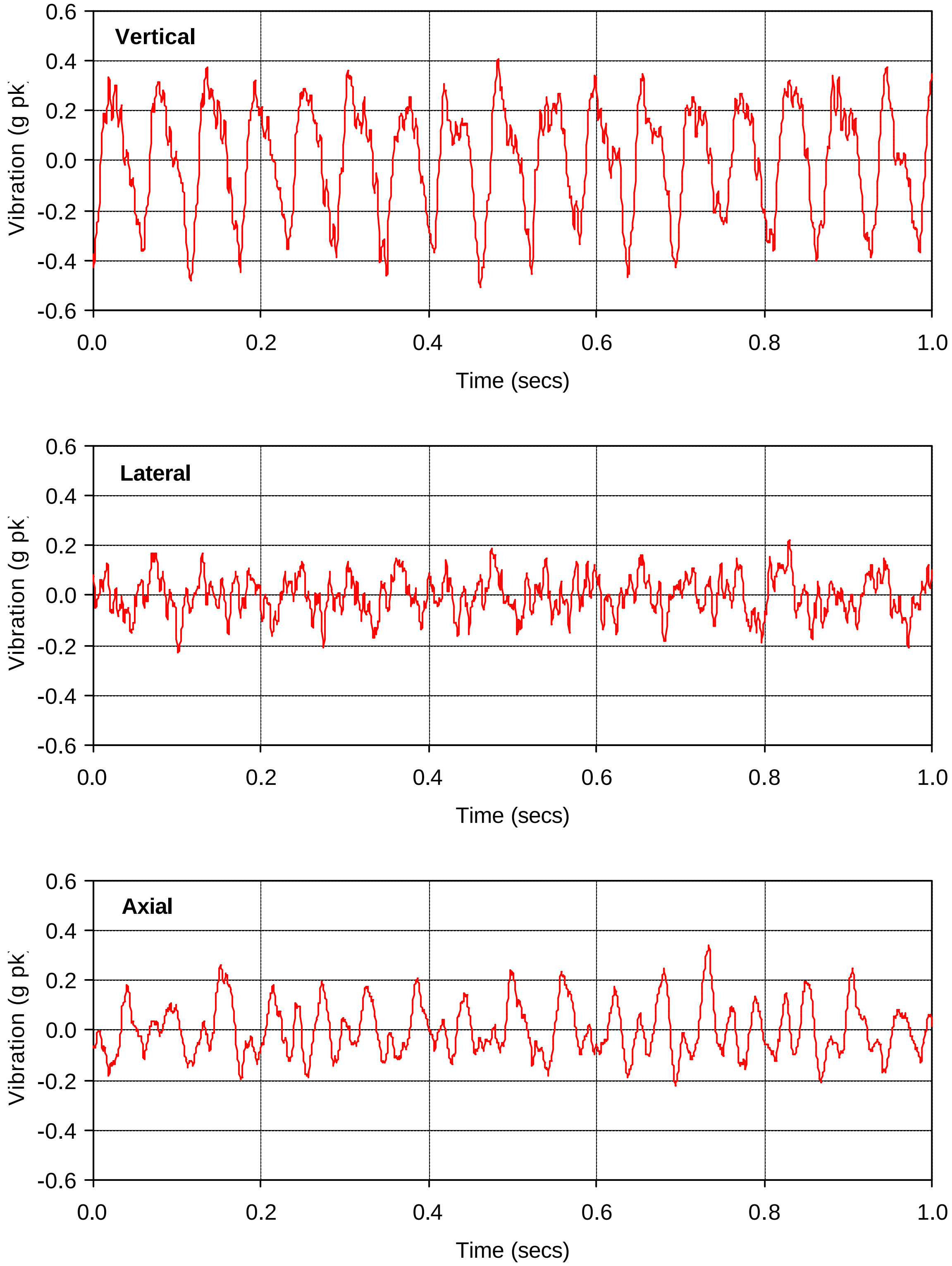


Figure 1 - Acceleration history of an externally carried store during straight and level flight on a Sea King helicopter

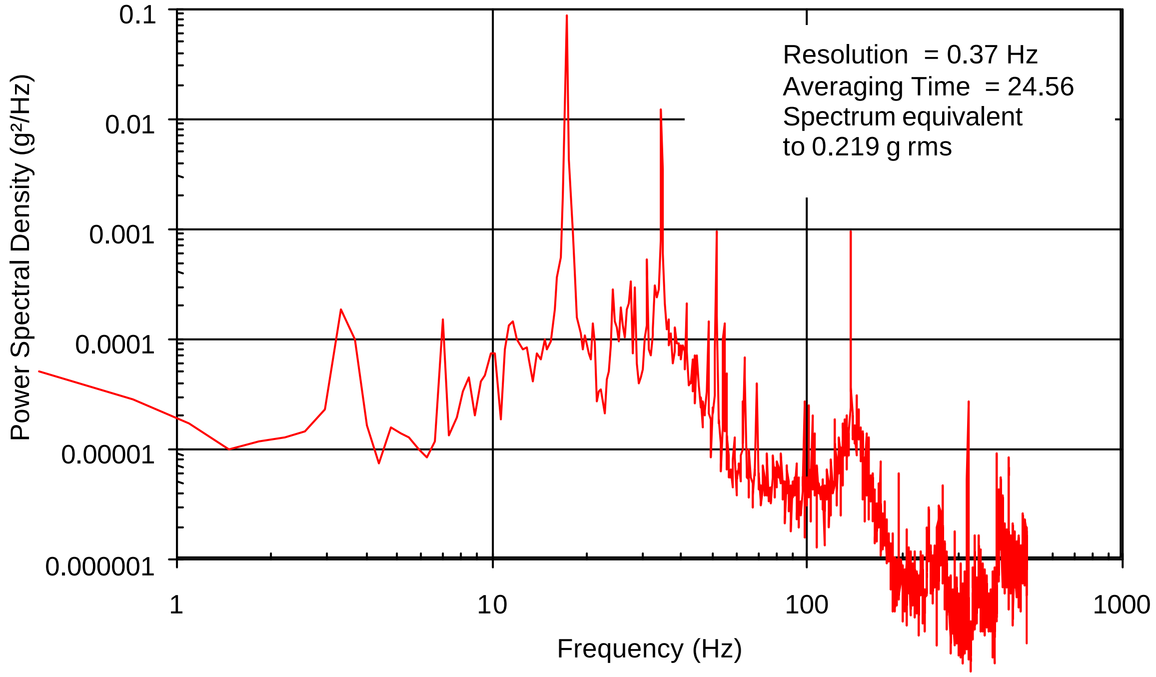


Figure 2 - Store vibration spectrum for external carriage on a Sea King helicopter

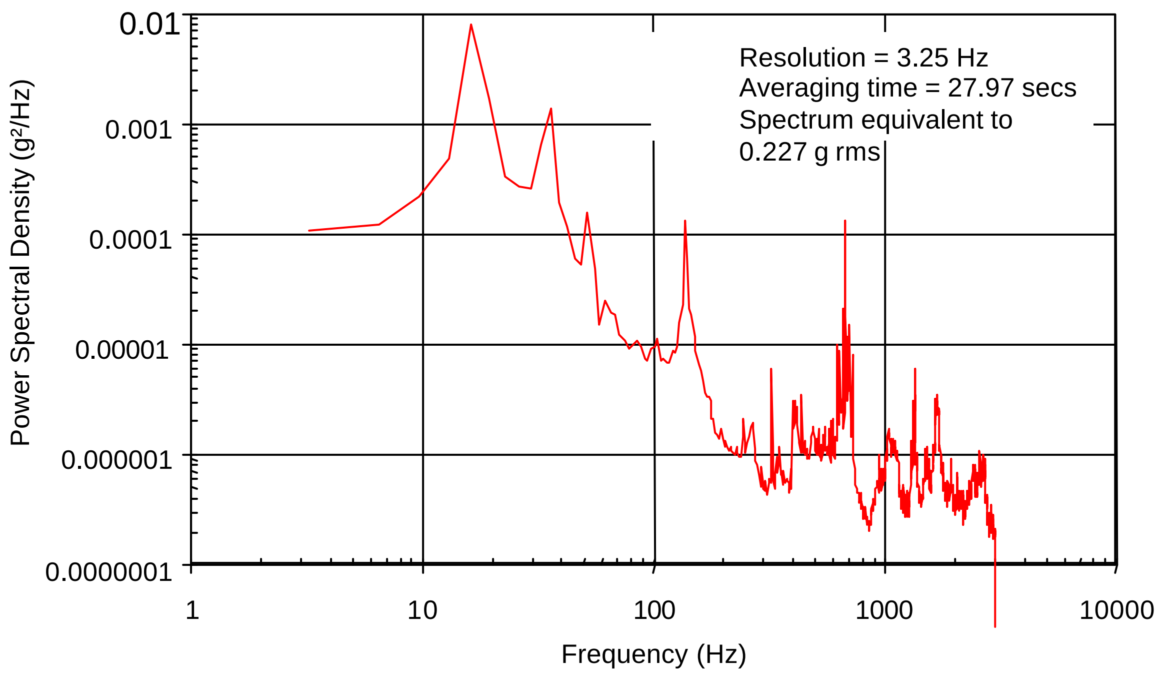


Figure 3 - Store wide band vibration spectrum for external carriage on a Sea King helicopter

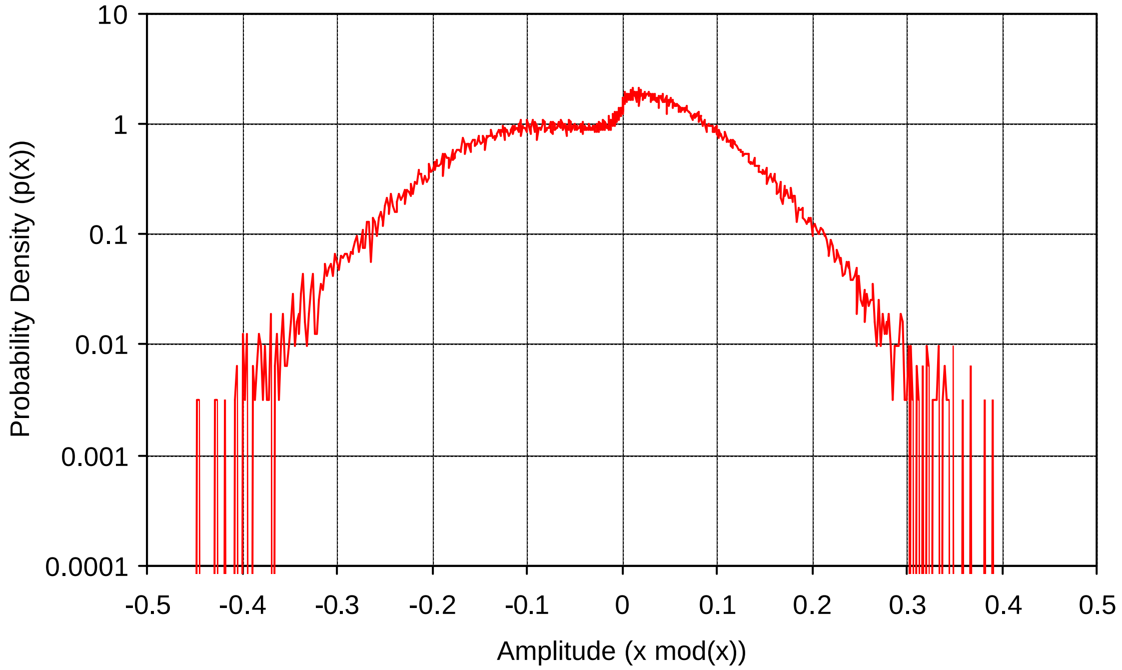
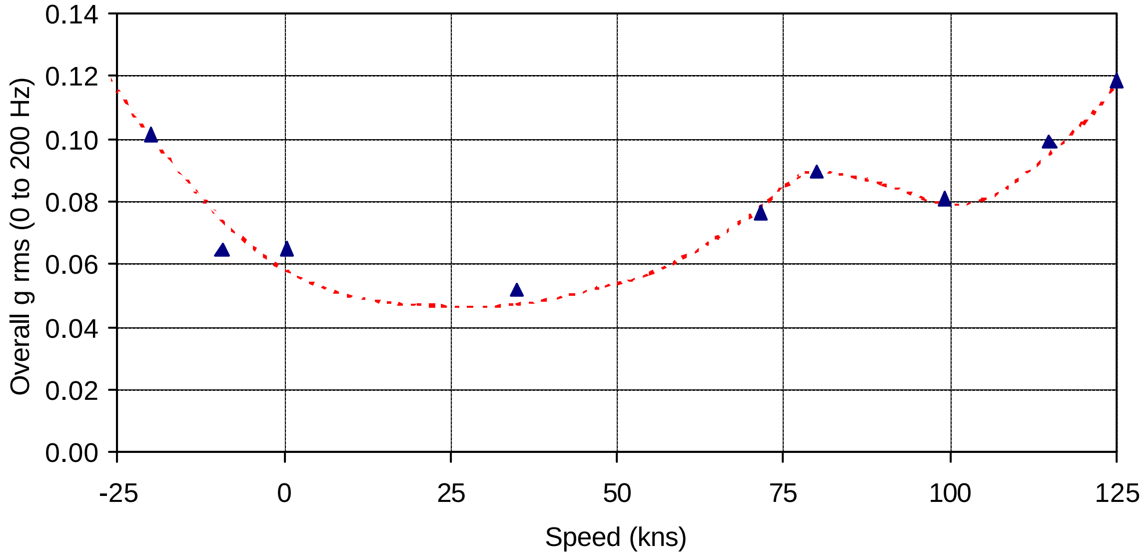


Figure 4 - Amplitude probability density for a store externally carried on a Sea King helicopter



Note: Data from an externally carried store on a Lynx helicopter

Figure 5 - Helicopter vibration versus speed characteristic

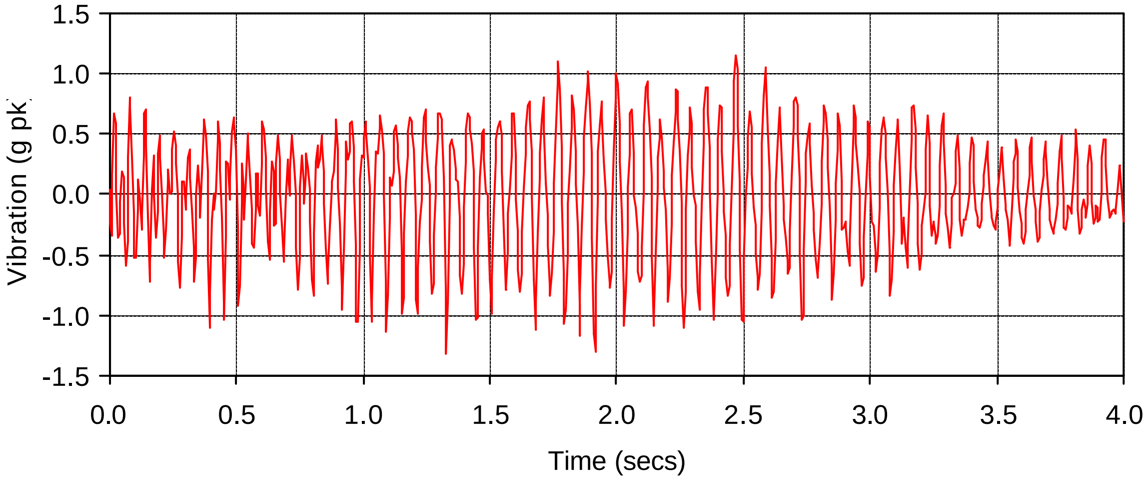


Figure 6 - Store acceleration history for transition from forward flight to hover

PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 Taxi Operations

A.1.1 During taxi operations around an airfield, a helicopter can be expected to experience vibration and transient inputs arising from the interaction of the wheels of the helicopter's undercarriage with the surface of the runway. The severity and character of these inputs will be dependent upon the mass of the helicopter, the size of its wheels, the compliance of its undercarriage and the quality of the runway surface. This environment may not be applicable to all helicopter types, such as those types fitted with skids in place of wheels.

A.2 Take-Off and Landing

A.2.1 The characteristics and severities arising from these conditions are generally encompassed by those of flight (see below). A possible exception is that of arrested landing, such as may occur on the flight deck of a ship.

A.3 Flight Conditions

A.3.1 For materiel installed either internally or externally on helicopters the dominant source of vibration is that associated with the main rotor blade passing frequency. Depending upon the position of materiel within the airframe, significant vibration response levels can occur at the frequencies of associated higher harmonics and also, albeit usually at lower levels, the main rotor, and the tail rotor and its blades. Excitation over a wide frequency range also arises from the action of other rotating components, such as drive shafts, engines, pumps and gear tooth meshing.

A.3.2 A notation system has evolved for describing the various rotational frequencies. If R is the rotational speed of the main rotor and n is the number of blades, then the blade passing frequency is given by nR, and subsequent harmonics are 2nR, 3nR, etc. Similarly, for the tail rotor, blade passing frequencies are denoted by nT, 2nT, etc., where T is the rotational speed of the tail rotor and n denotes the number of blades.

A.3.3 A typical vibration spectrum measured on a helicopter could include components from the following sources:-

Source	Frequency Range (Hz)
Ride motions, effects of turbulence	0-3
Main Rotor R	3-7
Fuselage bending modes	5-8
Rigid body modes of external stores on their carriers	6-20
Main Rotor blade passing nR	11-26
Tail rotor T, multiples of nR, tail drive shaft, pumps, gearboxes	8-80
Tail rotor blade passing nT, Pumps, engines and gearbox, output shafts	100-140
Main gearbox tooth meshing	450-700
Further gearbox tooth meshing frequencies	1000-5000
Engine turbine blades passing	10000-plus

A.3.4 For a dual rotor helicopter such as the Chinook, the dominant frequency tends to be the frequency of interaction between the two sets of blades, that is at 2nR.

A.3.5 Vibration can originate from several mechanisms associated with the action of the rotor system. Some of these mechanisms generate vibration directly while others first generate noise which produces vibration when it impinges on the helicopter's airframe. Because of the diverse nature of these sources, and their interactions, measured vibration spectra can appear complicated and possess features which are not easily explained, such as the cancelling or enhancement of certain blade passing harmonics. Some of these sources of vibration are:

a. Rotating Pressure Fields: Pressure fields rotating with the rotor blades produce noise which in turn produces periodic vibration at the blade passing frequency and harmonics when it impinges on the helicopter's fuselage.

b. Vortices: Vortices shed from the tips of the rotating blades cause broad band random vibration when they impinge on the helicopters fuselage.

c. Blade Thickness Noise: This noise is generated by air moving out of the way of an advancing blade and then returning after the blade has passed. This pulsation of noise is perceived at the fuselage as noise at the blade passing frequency, and can produce periodic vibration in the helicopter's structure.

d. Mechanical Imbalance: Periodic vibration is caused by mechanical imbalance of a rotor assembly and will be apparent at the rotor shaft speed and its harmonics. Imbalance can arise through the natural action of erosion over a period of time. Routine maintenance should act to minimise this vibration but some residual imbalance is likely.

e. Airflow Interference: When a rotor is producing lift, an airflow streams below it. If this flow is interfered with, eg: by the helicopter's tail boom, vibration can be induced into the rotor blades and transmitted to the helicopter's structure via the rotor bearing.

f. Rotor Blade Modes: Blade modes can be excited by forcing functions such as the air moving through the rotor disc or by airflow interference. If there is coupling between the blade mode frequencies and the forcing functions then the blades vibrate with large amplitude and there is little reaction at the rotor bearing. If the frequencies are well separated, however, the blades will suffer forced vibration which will be transmitted to the helicopter fuselage via the rotor bearing.

A.3.6 The rotor system assembly itself has inherent periodic vibration generating characteristics. In forward flight, the rotor blades experience periodic changes in loading because of their rotation in relation to the forward velocity of the helicopter and also to changing angles of attack.

A.3.7 Aerodynamic excitation of materiel, arising from the motion of the helicopter through the air, is not deemed to be significant because of the relatively low flight speeds of helicopters. However, this may not always be the case as blade technology improves and the speed of helicopters increases.

A.3.8 As for internally mounted materiel, that mounted externally experiences vibration which is predominantly mechanically transmitted from the rotor hub. Down-wash from rotor blades is not regarded as a significant excitation mechanism for external equipment. This is because, it is argued, it is the tips of the blades that generate most lift, and therefore, when in its usual mounting sites, externally carried materiel will tend to benefit from being in a region of less disturbed air.

SECTION 8

DEPLOYMENT ON SHIPS

SUB-SECTION 8/1 - DEPLOYED ON SURFACE SHIPS

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be encountered by materiel when deployed on, or installed in, surface ships powered by nuclear or conventional means.

1.2 The sources, characteristics and, where applicable, damaging effects of the mechanical environments are described. Guidance is contained in Annex A on the important factors influencing the mechanical environments.

1.3 The information within this sub-section refers only to surface ships of conventional hull design. Craft such as hydrofoils and hovercraft are not included.

1.4 Aspects relating to deployment or installation of materiel in surface ships that are not addressed in this sub-section are:

a. Hostile actions: Even though environments arising from hostile actions such as underwater or nuclear attack may drive major design parameters, they are outside the terms of reference of this STANAG. For guidance on such actions reference should be made to the procurement authority.

b. Propulsion systems: The environments experienced by equipment on the propulsion raft, induced by the operation of the propulsion system, are excluded. Reference should be made to the propulsion equipment supplier for guidance and data. The environments at the raft/vessel interface are included.

1.5 Vibration amplitude levels in surface ships are relatively benign. Moreover, stealth requirements demand ever decreasing levels. Another factor that acts to keep vibration levels low is the tolerance of the crew, because unlike tanks, trucks or aircraft, a ship’s crew lives on-board, sometimes for several months at a time.

1.6 The mechanical environments experienced by installed equipment arise from the actions of onboard machinery and of the sea. The following environments may be experienced.

2. ON-BOARD MACHINERY

2.1 The action of on-board machinery, including generators, transformers, propulsion engines, gearboxes, rotating shafts and propellers will induce vibration deployed on or installed in materiel. The vibration characteristics of this machinery, as experienced by the materiel will typically comprise excitations at discrete frequencies superimposed upon a background of broad band random vibration.

2.2 The excitations at discrete frequencies will correspond to the various rotational sources dependent upon the position of the materiel relative to these sources. Often, vibration at the propeller blade passing frequency, and its associated harmonics is relatively strong. These frequencies may change for different speeds according to the type of ship. For example, some ships achieve different speeds by varying both engine revolutions and propeller blade pitch angle according to a control law. A typical example of a vibration spectrum originating from the aft area of a UK anti-submarine frigate is presented in Figure 1. This figure also indicates the shaft order frequencies. Acceleration and ASD spectra from the aft area of a French anti-aircraft frigate is presented in Figure 2.

2.3 The broad band random component of a typical vibration spectrum will arise from the cumulative effect of all activity onboard ship, the prevailing sea condition and the influence of the ship's own dynamic response characteristics.

2.4 Although the vibration environment on-board ship is, for most materiel, benign, it should be noted that because of the operational deployment patterns for ships, materiel can be exposed to the environment continuously for several months. Consequently, the most common failure mechanisms likely to be encountered are of the time dependent variety such as high cycle fatigue, fretting and brinelling. These types of failure are of particular relevance to flexible and lightly damped components, which may have resonances in the range associated with a ship's propeller blade passing frequencies.

2.5 To protect against the effects of underwater attack, materiel is often fitted with shock mounts. Unfortunately, materiel mounted using these devices can consequently possess installed natural frequencies in the frequency range associated with onboard rotating machinery. If this coincidence of excitation and response frequencies occurs, then excessive materiel displacements can result. Such coincidence can lead to a degradation of the anti-shock mount and, of course, to the materiel.

3. WAVE SLAP

3.1 The effects of waves impacting on the ship's hull, ie: wave slap, can give rise to shock loadings. It is not usually necessary to carry out tests for these conditions. Any shocks that may be expected to occur are likely to be encompassed by those associated with handling events.

4. SEA SLAMMING

4.1 Slamming is a localised phenomenon occurring when the relatively flat underside of a ship's hull slaps onto the surface of the sea at a relatively high velocity when driving into heavy seas. It is therefore more applicable to materiel installed in the hull below the water line. Transient accelerations caused by slamming in frigates and larger ships can reach 1 g. In smaller ships, eg: mine-sweeper, transient accelerations up to 5 g have been recorded. It is not usually necessary to carry out tests on materiel for these conditions.

5. SHIP MOTIONS

5.1 The action of the sea and weather can give rise to cyclical motion at low frequencies (periods of several seconds) in roll, pitch and yaw. These motions are approximately simple harmonic with a natural period depending on the characteristics of the ship. Examples of values of ship motion for Sea State 7 are given in Table 1. Because the levels are so low it is not usually necessary to carry out tests for these conditions.

6. GUNFIRE AND LAUNCH OF WEAPONS

6.1 A ship's guns can cause a shock response in nearby equipment. This arises from the effects of blast and to a lesser extent, recoil. Blast is caused by the exit and rapid expansion of propellant gases following the emergence of the projectile from the gun's muzzle. These conditions, and those associated with the launch of missiles, are highly specific to the gun or missile type, and so the provision of generalised information regarding the need for tests is inappropriate.

6.2 The blast pressure wave associated with the action of gunfire can cause structural damage to the ship's structure close to the gun's muzzle, ie: in the near field. Also in this area, materiel close to the muzzle, but protected from the blast, may suffer the effects of the resulting mechanical shock associated with gun fire. Further from the gun's muzzle, ie: in the far field, materiel may suffer the effects associated with intense low frequency vibration corresponding to the gun fire rate. Possible adverse effects in this region could arise from a coupling of the gun firing rate with structural modes of vibration or with the installed natural frequencies of materiel.

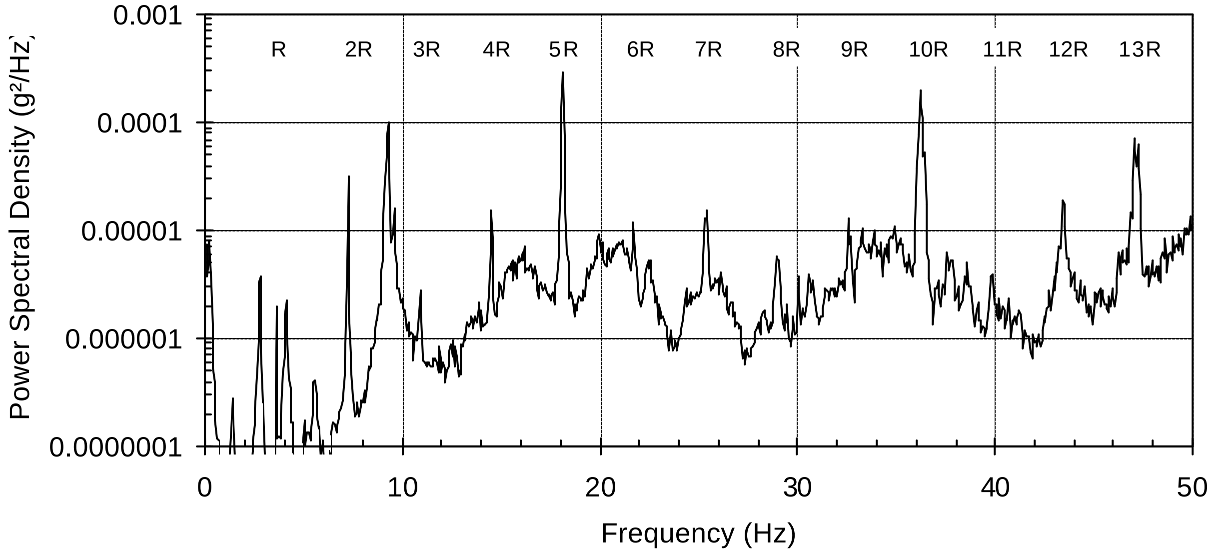
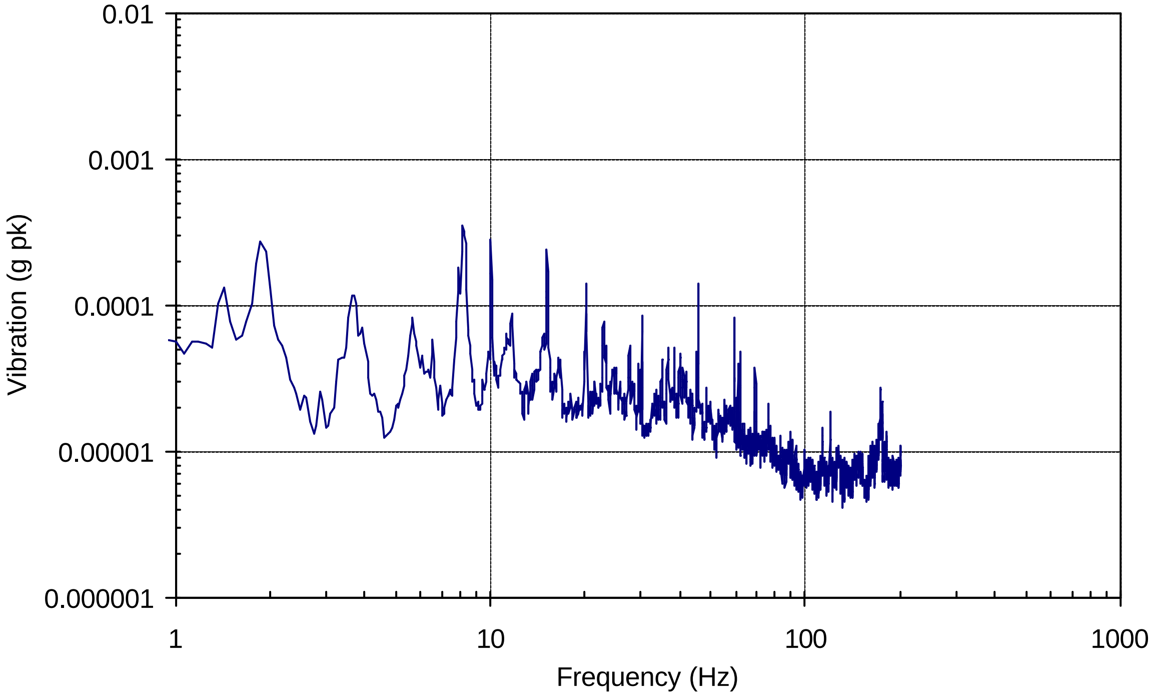
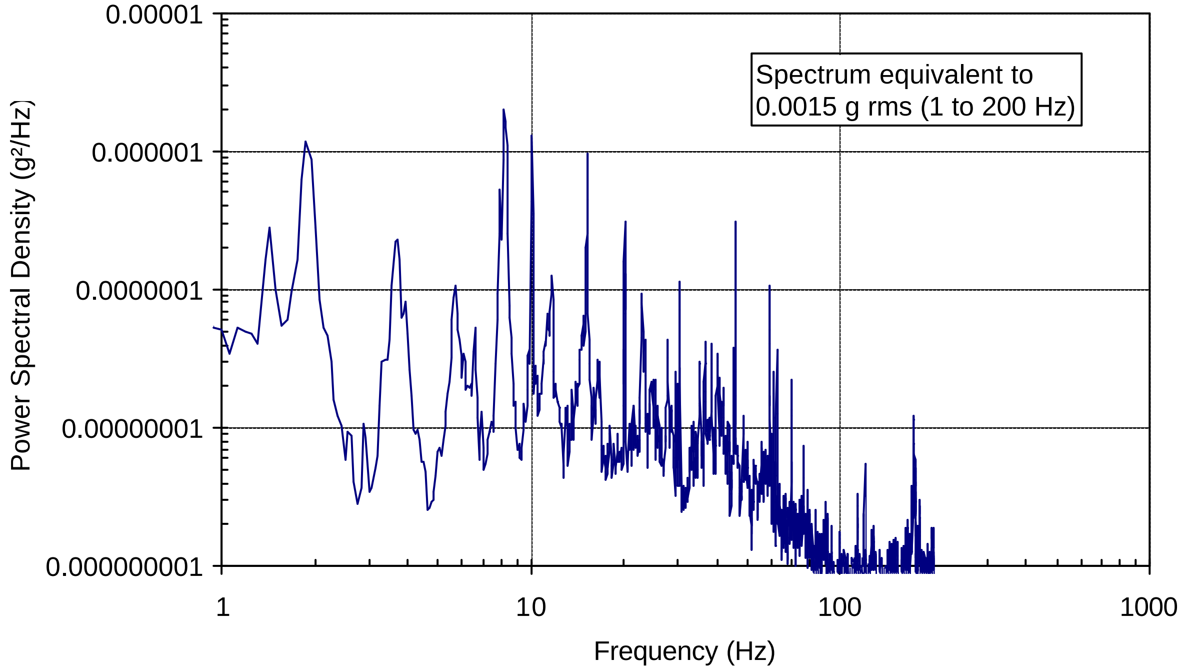


Figure 1 - Identification of propeller shaft frequency in a frigate's vibration spectrum



a. Peak hold (g pk) vibration spectrum



b. Mean power spectral density

Figure 2 - Vibration spectrum from an anti-aircraft (F70) frigate

Roll (Unstabilised)		Pitch		Yaw	Heave	
Period (s)	Amplitude (deg)	Period (s)	Amplitude (deg)	Acceleration under Ship's Motion (deg/s^2)	Period (s)	Amplitude (m)
10	±18	5 to 6	±8	1.75	7	±3.5

Table 1 - Ship motion data.

(Derived from UK specification NES 1004)

Notes:

1. *All data relates to Sea State 7, significant wave height 6 to 9 m.*
2. *These statistically significant values are defined as the average of the third highest peaks and there is a 13% probability of exceeding these values.*
3. *RMS values, which have a numerical value equal to half the significant value, are exceeded 60%.*

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PARAMETERS INFLUENCING THE MECHANICAL ENVIRONMENTS

A.1 General

A.1.1 Measured vibration data on onboard machinery will rarely be available for all in-service conditions. Therefore it is useful to establish, particularly for sensitive materiel, a working knowledge of the effects of various parameters on vibration severity. This is usually achieved by the derivation of empirical predictive models from the measured data acquired from a well planned programme.

A.1.2 Vibration amplitudes on small ships, such as motor torpedo boats, can be relatively high because of their high performance. Also, being small means that transmission paths will be short from machinery to materiel and so the attenuation of vibration will be limited. Whilst larger ships would be expected to give rise to a more benign vibration environment than small ships, aircraft carriers are a special case. This arises from their high performance requirements demanding powerful propulsion systems. Aircraft operations, such as take-off and landing, can also induce vibration and shock loads into the ship's structure.

A.1.3 Due to the relatively benign environments arising from the conditions addressed in this sub-section, the following parameters are limited to those relating only to the transmission of vibration from on-board machinery, whether or not anti-shock mountings are used on the installed materiel.

A.2 Ship Operation

A.2.2 Speed: Vibration can be expected to increase with increasing speed, although maximum vibration may not necessarily coincide with maximum speed. Rather than speed, a better parameter here might be power demand, or the position of the Power Control Lever (PCL). Some ships respond to power demands by altering both engine speed and propeller pitch according to pre-set control laws. Figure A1 presents data obtained from a frigate which illustrates how vibration can vary according to PCL setting; corresponding ship speeds are also indicated on the figure.

A.2.3 Asynchronous Running: Some ships are fitted with multiple propulsion lines and sometimes run with only one line powered and one line "training", called asynchronous running. Differences in vibration severity between asynchronous and synchronous running can occur.

A.2.4 Engine Configuration: Some ships are fitted with multiple engines per propulsion line. Differences in vibration severity can be expected according to which engine configuration is in use.

A.2.5 Turns: Turns to port and starboard can be expected to be equally severe and of greater severity to the equivalent ahead condition, as illustrated in Figures A2 and A3.

A.2.6 Emergency Stop: This condition can be expected to give rise to relatively severe vibration, albeit for only short durations. An acceleration (g rms) time history for an emergency stop is presented in Figure A4.

A.2.7 Astern: Vibration associated with this condition can exceed that of full ahead, although as for the crash stop, vibration tends to be non-stationary in character.

A.3 Action of the Sea

A.3.1 Sea Depth: For a given condition vibration is likely to be more severe in shallow compared to deep water because of reflections from the sea bed. Shallow water is generally regarded to be of depth less than five times the draught of the ship.

A.3.2 Sea State: The general vibration environment onboard ship can be expected to become more severe with increasing sea state. This can arise as a result slamming, wave slap and increased demands on the propulsion system. In rough seas, when the ship may roll and pitch, the depth of the propellers beneath the water will vary, which will modify the vibration characteristics and may produce cavitation noise.

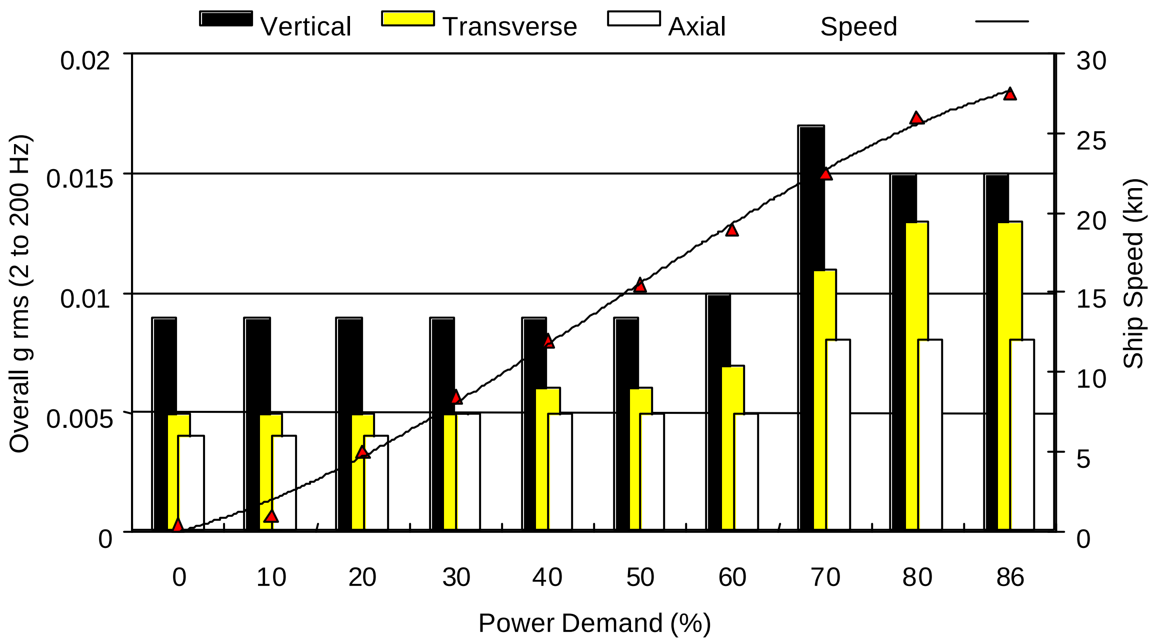


Figure A.1 - Vibration severity (g rms) versus power demand

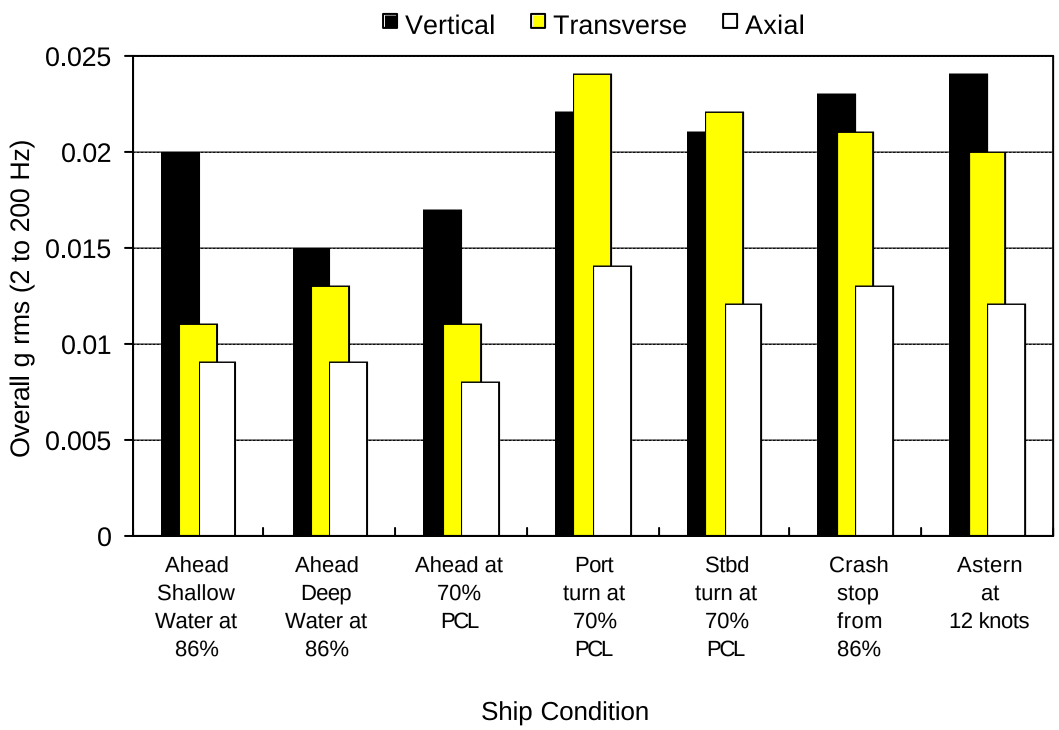


Figure A2 - Comparison of the effects of various ship conditions

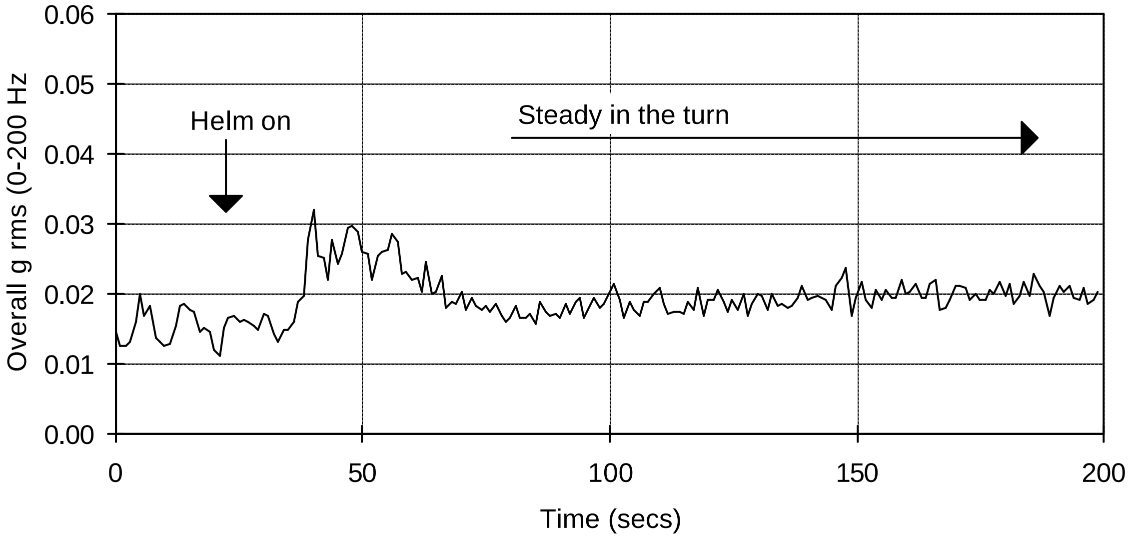


Figure A3 - Ship structural vibration response for a starboard turn

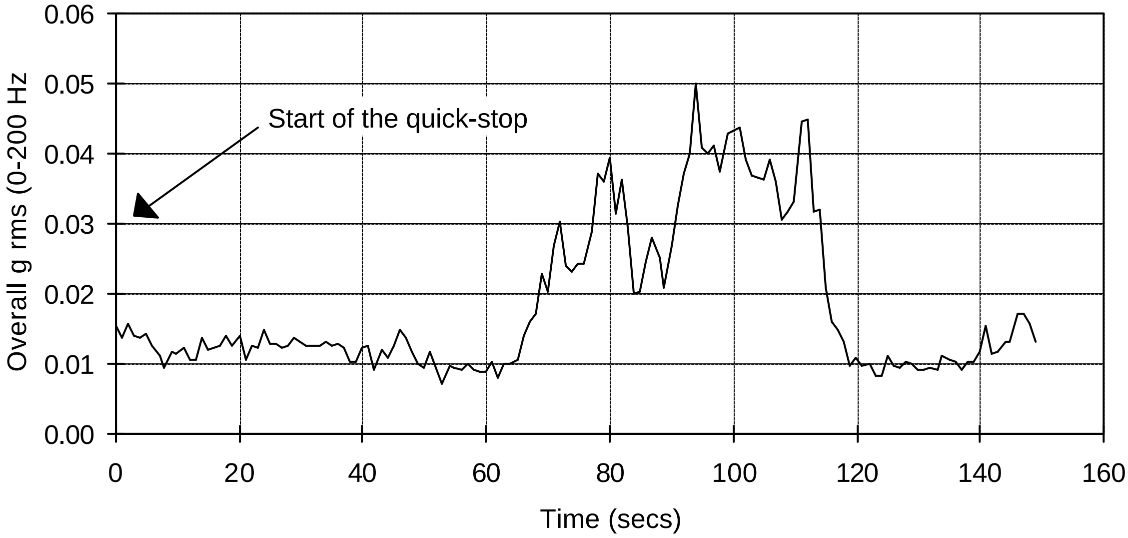


Figure A4 - Ship structural vibration response for a quick-stop

SUB-SECTION 8/2 - DEPLOYED IN SUBMARINES

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be encountered by materiel when deployed on, or installed in, submarines (nuclear or conventionally powered). The sources, characteristics and, where applicable, damaging effects of the mechanical environments are described.

1.2 Aspects relating to deployment or installation of materiel in submarines that are not addressed in this leaflet are:

a. Hostile actions: Even though environments arising from hostile actions such as underwater attack may drive major design parameters, they are outside the terms of reference of this STANAG. For guidance on such actions reference should be made to the procurement authority.

b. Propulsion systems: The environment experienced by materiel on the propulsion raft, induced by the operation of the propulsion system, is excluded. Reference should be made to the propulsion equipment supplier for guidance and data. The environment at the raft/vessel interface is included.

1.3 The operation of submarines gives rise to a range of mechanical environments. The severity of a particular environment is influenced by the location of the subject materiel with respect to a source of the environment. The following paragraphs address a number of generalised sources.

2. HYDROSTATIC EFFECTS

2.1 Materiel subjected to diving pressure either inside or outside the pressure hull will, during sub surface operation, be subjected to severe hydrostatic pressure. Materiel is expected to survive or operate as required when subjected to the Depth Dependant System Test Pressure. Typically materiel is expected to withstand cyclic stress changes in the order of 2.10^4 cycles.

3. WATER MOTION

3.1 Subsurface Fluid Motion: Fluid motion of the sea in the vicinity of a submarine will cause the vessel to adopt a rigid body cyclical motion at low frequencies in roll, pitch, yaw and heave. These cyclical motions approximate to simple harmonic motion (SHM) with a natural period (of several seconds) depending upon the characteristics of the vessel. To accommodate any variances from SHM, the velocities and accelerations calculated using SHM theory should be multiplied by a factor, typically a value of 1.5 is used. Limit severities are indicated in Table 1.

3.2 Wave Slap: During surface transit, wave motion will subject external structures situated above the waterline, eg: rudders, hydroplanes and masts to a severe distributed loading. This loading is usually treated as a quasi-static condition. The choice of the design pressure loading is based on the implications of the potential failure mode under consideration. If the failure would result in a breach of the pressure hull boundary, then the design pressure should normally have a probability of occurrence of less than one in ten thousand. If the failure would result in loss of system function only, then a probability of one in one hundred is usually acceptable. Design pressures of 58.1 and 48.8 kPA respectively can arise from such a rationale. The pressures are assumed to apply to the projected areas of the structures under consideration.

4. SUBMARINE MOTION - VIBRATION

4.1 Tactical considerations demand that submarines produce extremely low levels of vibration. Moreover, operating procedures are optimised to ensure minimisation of noise. Factors that contribute to limiting such dynamic responses are:

a. Double skin construction

b. Surface coatings on hull outer surface

c. Laminar flow hull design

d. Careful balancing of rotating components

e. Fine bladed large diameter propellers

f. Isolation of machinery/equipment from main structure

4.2 Vibration measured during instrumented trials of submarines indicate the dominance of periodic vibration at frequencies associated with the propeller blade passing frequency, ie: the shaft rotation frequency multiplied by the number of propeller blades. Since the speed of submarines is varied by controlling the shaft speed, measured vibration severity will vary with the forward speed of the craft, as illustrated in Figure 1.

4.3 For materiel particularly sensitive to vibration, the usual approach for qualification using fallback test severities may not be appropriate. In such circumstances it will be necessary during equipment development to characterise the environment pertaining to the particular installation. Both long term vibration and transient events should be considered when producing such an environmental description.

a. Long Term Vibration: The long term vibration environment at materiel locations will vary with the forward speed of the submarine and will be dominated by the local structural response at the propeller blade passing frequency. Typically, responses will be ± 0.1 g peak and of a periodic nature. Figure 1 illustrates a typical response on a submarine weapon bay structure as a function of the forward speed of the craft. With knowledge of the distribution of forward speed with operational time, a full description of the long term vibration environment may be achieved. The procurement authority should be consulted to provide the speed versus blade passing frequency relationship and the speed versus duration distribution.

b. Transient Events: The effects of transient events such as adjacent weapon release cannot be generalised and therefore specific measurements and/or analyses should be undertaken as appropriate.

4.4 The vibration environment on-board submarines, for most materiel, is benign. However, it should be noted that because of the operational deployment patterns for submarines, materiel can be exposed to the environment continuously for several months. Consequently, the most common failure mechanisms likely to be encountered are time dependent, such as high cycle fatigue, fretting and brinelling. These types of failure are of particular relevance to flexible and lightly damped components, which may have resonances in the range associated with the vessel's propeller blade passing frequencies.

4.5 To protect against the effects of underwater attack, materiel is often fitted with shock mounts. Unfortunately, materiel mounted using these devices can consequently possess installed natural frequencies in the frequency range associated with onboard rotating machinery. If this coincidence of excitation and response frequencies occurs, then excessive materiel displacements can result. Moreover, such coincidence can lead to a degradation of the anti-shock mount.

5. SUBMARINE MOTION - MANOEUVRES

5.1 Tactical manoeuvres adopted by some submarines can cause a “Snap Roll” condition, ie: a sudden and rapid rate of roll about the vessel longitudinal axis, which occurs during the initial transient phase of a submerged high speed turn. Such manoeuvres produce a roll amplitude of up to ± 25 degrees with a period of around 7 seconds.

6. STATIC TILT

6.1 Submarine operations may result in the vessel adopting an angle of heel or trim up to approximately 30 degrees for extended periods. Equipment is normally expected to be capable of satisfactory operation under such circumstances.

7. ON-BOARD MACHINERY

7.1 The operation of on-board machinery has the potential to cause vibration that could be transmitted to the submarine structure. However, the requirement for silent operation dictates that such machinery is anti-vibration mounted and usually sited on a raft. For information on permissible raft environment severities, reference should be made to the procurement authority.

8. LAUNCH, FIRING OF WEAPONS AND COUNTERMEASURES

8.1 Materiel may be subjected to the effects of launch and firing of weapons and countermeasures, particularly materiel situated on the outer surface of the submarine, above the waterline, during surface operations. The effects of such actions are specific to the particular location of the materiel and weapon in question.

Type	Roll		Pitch		Yaw	Heave	
	Period (s)	Amplitude (deg)	Period (s)	Amplitude (deg)	Acceleration under Ship’s Motion (deg/s^2)	Period (s)	Amplitude (deg)
C	6	±25	11	±5	Small - insufficient data	11	3
N	7	±25*	11	±5		11	3

Table 1 - Submarine motion data

(Derived from UK Specification NES 1004)

Notes:

1. *C denotes a conventionally powered submarine.*
2. *N denotes a nuclear powered submarine.*
3. *All data relates to Sea State 7, significant wave height 6 to 9 m.*
4. *These statistically significant values are defined as the average of the third highest peaks and there is a 13% probability of exceeding these values.*
5. *RMS values, which have a numerical value equal to half the significant value, are exceeded 60%.*
6. **denotes a snap roll manoeuvre.*

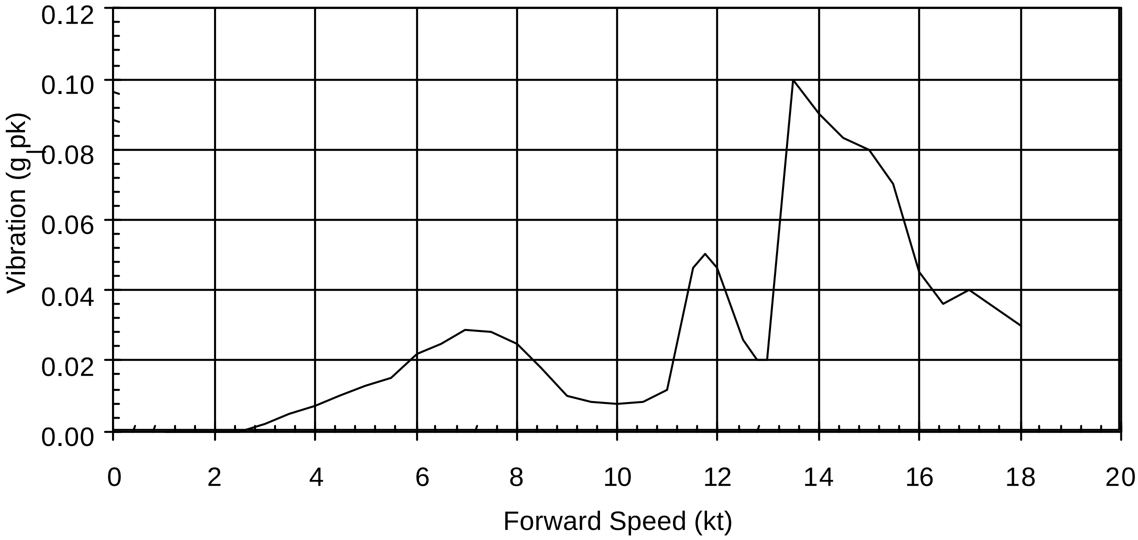


Figure 1 - Structural vibration response versus forward speed

SECTION 9

WEAPONS

SUB-SECTION 9/1 - AIR AND SURFACE WEAPONS

1. GENERAL

1.1 This sub-section addresses the mechanical environments that may be encountered by air and land weapons, including guided missiles, bombs and projectiles during their separation from the host platform and during their autonomous flight to the target. The sources and characteristics of the mechanical environments are presented and discussed, and where applicable advice is given on potential damaging effects.

2. AIR LAUNCH - EJECTION TRANSIENTS

2.1 Severe transient accelerations are induced in air launched stores during their release by cartridge powered ejection release units (ERUs). The purpose of ERUs is to ensure the safe release of stores from high performance aircraft. Other devices, such as the various gravity release units used for releasing munitions from helicopters, and rail launchers used for releasing some types of guided weapons from aircraft, do not themselves induce significant transient loadings into munitions.

2.2 Depending upon the particular aircraft/store combination, transients applied to munitions by ERUs can attain acceleration levels up to 40 g, whilst pulse shapes are broadly half sine and durations typically within the range 10 to 40 ms. Ram ejection forces can attain 50 kN. Typical ram force time histories are shown in Figure 1. Further information is referenced in AECTP 200 249/1.

2.3 The relatively high amplitudes and long durations of these pulses often produce critical design load cases. Consequently modelling and/or test firings are used to derive project specific, ie: tailored, load-time plots to which materiel is qualified. General purpose fall back or minimum integrity levels for design are not appropriate for ejection transients.

3. AIR LAUNCH - RELEASE DISTURBANCE

3.1 During release of the store from an aircraft any asymmetric ERU ejection forces will cause significant store pitching motions which will result in substantial aerodynamic pressure and acceleration forces being imparted to the store.

3.2 Aerodynamic design requirements for stores should ensure that these release disturbance forces are quickly damped out. Nevertheless, the applied forces experienced by the stores can attain relatively high amplitudes and long durations, which may result in critical design load cases. Therefore modelling and/or wind tunnel testing are used to establish project specific, ie: tailored, loads to which materiel is qualified. Fall back or minimum integrity levels are not appropriate for this condition.

4. LAND VEHICLE LAUNCH

4.1 No additional severe weapon loadings are attributed to this launch mode, other than those associated with materiel deployed on vehicles (See Section 5). However, a detailed knowledge of vehicle motions during launch is usually essential for weapon performance considerations.

5. GROUND/SILO LAUNCH

5.1 During launch the reflection of motor efflux from the launch pad/silo surfaces can generate severe transient acoustic and vibration levels throughout a weapon, which for some weapons can result in the highest operational vibration levels.

5.2 The amplitudes and durations of these transients are of course unique to the particular store design, and therefore it is not appropriate to quote fall back levels for these events. Nevertheless, because of the high levels generated it is important to conduct measurements as early as possible to confirm design assumptions.

6. GUN BARREL LAUNCH

6.1 Very high acceleration forces, say, of the order of 20,000 g, can be induced longitudinally in gun launched munitions whilst traversing the length of the barrel. In addition, they can be subjected to high lateral acceleration forces, often to a similar order of magnitude, and also to a very high spin rate. Therefore, these munitions require special and/or live firing facilities with which to undertake design proving and equipment qualification trials.

7. OTHER LAUNCH MODES

7.1 Other launch modes such as the launch of a munition from the deck of a surface ship is addressed in Sub-section 9/2, paragraph 5.1.

8. POWERED FLIGHT

8.1 During the powered flight phase certain missile elements and units, particularly those sited adjacent to the motor system, may be subject to severe vibration arising from propellant combustion and gas dynamics. This vibration often comprises two phases, ie: a high level short duration period arising from the boost phase, followed immediately by a lower level longer duration period arising from the sustain phase. Vibration responses tend to be project specific because of the unique performance characteristics required of each missile/motor combination. Consequently, it is impractical to cover all combinations in this sub-section. However, the basic characteristics of typical vibration spectra are described, and typical severities are indicated.

8.2 For a missile powered by a solid propellant motor the observed vibration spectra for equipment installed forward of the motor is predominantly broad band random and typically of the form illustrated in Figure 2. Propellant cavity induced resonances may sometimes be evident as sine-like excitations. Levels much higher than those shown in Figure 2 may exist in high thrust missiles. Liquid propellant motors also produce predominantly broad band random vibration at their nozzles. However, in ramjet powered missiles the observed vibration spectra on similarly sited equipment may be dominated by sine-like excitations, as shown in Figure 3, arising from the inherent cavities.

8.3 For units sited towards the rear of a high speed missile, powered by a solid propellant motor the powered flight vibration levels can be the most severe that units will experience. Moreover, it should be noted that the measured vibration spectra will include also the responses arising from the turbulent air flow traversing the missile. A typical vibration spectrum for units sited towards the rear of a missile is shown in Figure 4. Acceleration responses (rms g) arising from turbulent airflow are generally proportional to dynamic pressure (q), and are described in Sub-section 6/2. For equipment sited towards the front of a high speed missile the vibration levels arising from the motor may not be particularly severe, and may not differ significantly from those arising from turbulent airflow. A typical vibration spectrum for forward sited equipment is also shown in Figure 4. For equipment located towards the rear of a missile significant vibration levels extend out to frequencies of around 5 kHz, whilst for forward located equipment the attenuation at the higher frequencies has effectively reduced the frequency range to 2 kHz.

9. FLIGHT MANOEUVRES

9.1 Whilst manoeuvring after launch a missile can be subjected to severe acceleration loads. Some intelligent submunitions may also incur such loads. The duration of a manoeuvre is relatively long and therefore its maximum acceleration value can usually be treated as a quasi-static load condition. Because these manoeuvres are unique for a missile type, no fall back severities are suggested for these conditions.

9.2 Where novel thrust devices are used to induce missile manoeuvres, the forcing actions should be evaluated for any significant transient accelerations.

10. UNPOWERED FLIGHT

10.1 Few data are available on vibration levels during the unpowered flight phase of a missile or store. Nevertheless, it is usually assumed that unpowered flight vibration levels will not exceed those during powered flight, discussed above, or those during flight carriage, provided that the dynamic pressure when unpowered does not exceed that for powered flight or flight carriage.

11. SEPARATION AND STAGING

11.1 During missile separation and staging events the initiation of pyrotechnic devices, such as explosive bolts and line cutting charges, often result in severe shock loadings, which can take the form of stress waves and/or oscillatory acceleration transients.

11.2 Materiel sited close to a pyrotechnic source may be subject to high amplitude stress waves. This situation is likely where the measured acceleration data appear to be dominated by high frequency peaks, such as those shown in Figure 5. In these cases test methods that subject equipments to acceleration transients are inappropriate; and consequently, special purpose test apparatus is usually necessary. One solution is to use a gas gun facility to fire projectiles at a platform on which is mounted the materiel for testing. The test severity may be controlled by monitoring strain histories on the platform. The preferred solution is to conduct a number of live firings, and to compensate for actual rather than factored test levels by analysing the monitored test severities and the performance of the materiel on a statistical basis.

11.3 Materiel sited some distance from a pyrotechnic source will be subject to the effects of the structure responding to the excitation. This situation is identified from measured data where the responses appear to be dominated by structural resonances, as is shown in Figure 6.

11.4 Comprehensive information on many aspects of pyrotechnic shock, including shock levels, their measurement, attenuation and simulation, is referenced in AECTP-200 Leaflet 249/1. Nevertheless, due to the diverse nature of the shock mechanisms associated with pyrotechnic devices it is inappropriate to quote generalised fall back severities for design or test purposes.

12. SPIN

12.1 To increase stability some projectiles or submunitions are subjected to spin during release. Spin rates vary considerably depending upon performance requirements. Therefore, it is inappropriate to recommend general purpose test methods or spin rates. Special purpose test facilities, such as using a motorised device to induce spin, may be required to induce high rates.

13. PARACHUTE RETARDATION

13.1 Parachute retarded projectiles are usually subjected to two significant acceleration transients during parachute deployment. The first transient is a snatch condition that occurs when the uninflated canopy is arrested by the rigging lines at the instant of full deployment. The second transient arises from the rapid increase in deceleration force during the inflation of the canopy. Both transients are illustrated in Figure 7 and comprise, in the main, relatively low frequency components. Therefore these transients can often be treated as quasi-static load conditions.

13.2 It should be noted that transverse load components can be induced in a munition from both snatch and inflation events. Comprehensive information on parachute snatch and inflation loads is referenced in AECTP-200 Leaflet 249/1. Due to the wide range of operational uses for parachute systems, it is inappropriate to quote generalised fall back test severities.

14. WATER ENTRY

14.1 These conditions are addressed in Sub-section 9/2.

15. SUBMUNITION EJECTION

15.1 To achieve the required deployment patterns, submunitions may be ejected from their host store by explosive devices. Typically such devices comprise cartridge powered launch tubes or piston assemblies. The acceleration transients arising from these devices can be severe, typically around 1000 g. Pulse durations are of the order of 10 ms, whilst pulse shapes are broadly of the form of half sines. Since these ejection devices are tailored to suit specific performance requirements, it is inappropriate to quote generalised fall back design and test severities. However, severities can usually be derived from theoretical predictions, and where necessary supported at a later stage by experimental data.

16. SUBMUNITION IMPACT

16.1 Submunitions required to survive ground impact after deployment from a dispenser are likely to experience high accelerations and fast acceleration rise times during such an event. A typical example of an acceleration time history for a submunition during impact and penetration of concrete is shown in Figure 8, where levels of 60,000 g are experienced within 0.0001 secs.

16.2 Considerable development testing may be necessary to produce a satisfactory design. This testing may require a purpose built gas gun or catapult device which can in many cases provide a very realistic environment at a relatively low cost. Consequently, special purpose test apparatus, rather than standardised test procedures, are usually more appropriate for testing equipment to such impact conditions.

17. NOVEL APPROACHES

17.1 It is not possible within this AECP to address all the environmental conditions and particularly those that arise from novel approaches to weapon design. Moreover, it is usually necessary to conduct particular data acquisition programmes and to devise special test facilities for the conditions arising from novel approaches.

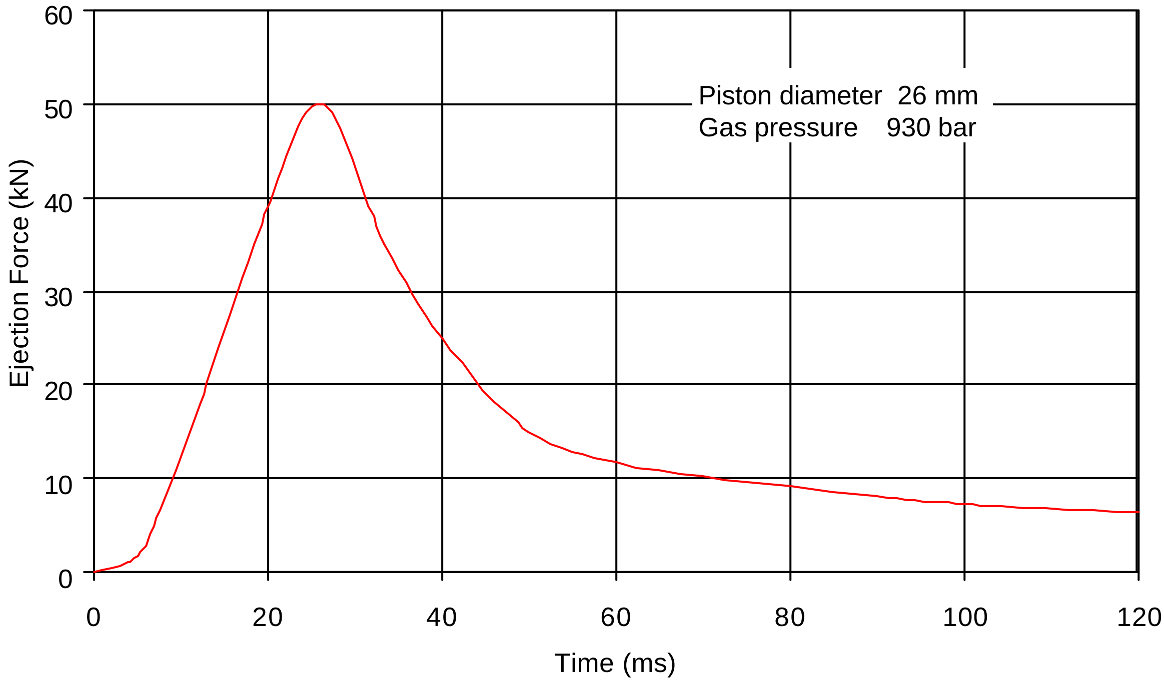


Figure 1 - ERU ejection transient

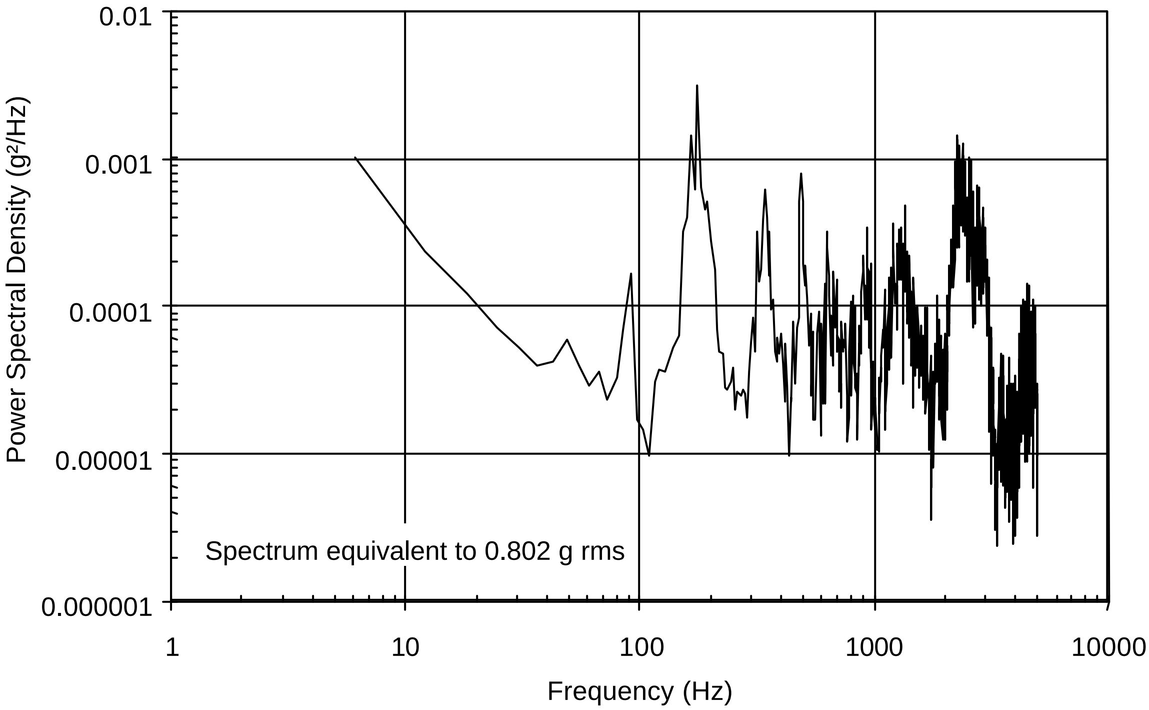


Figure 2 - Spectral responses of missile equipment adjacent to a solid propellant rocket motor

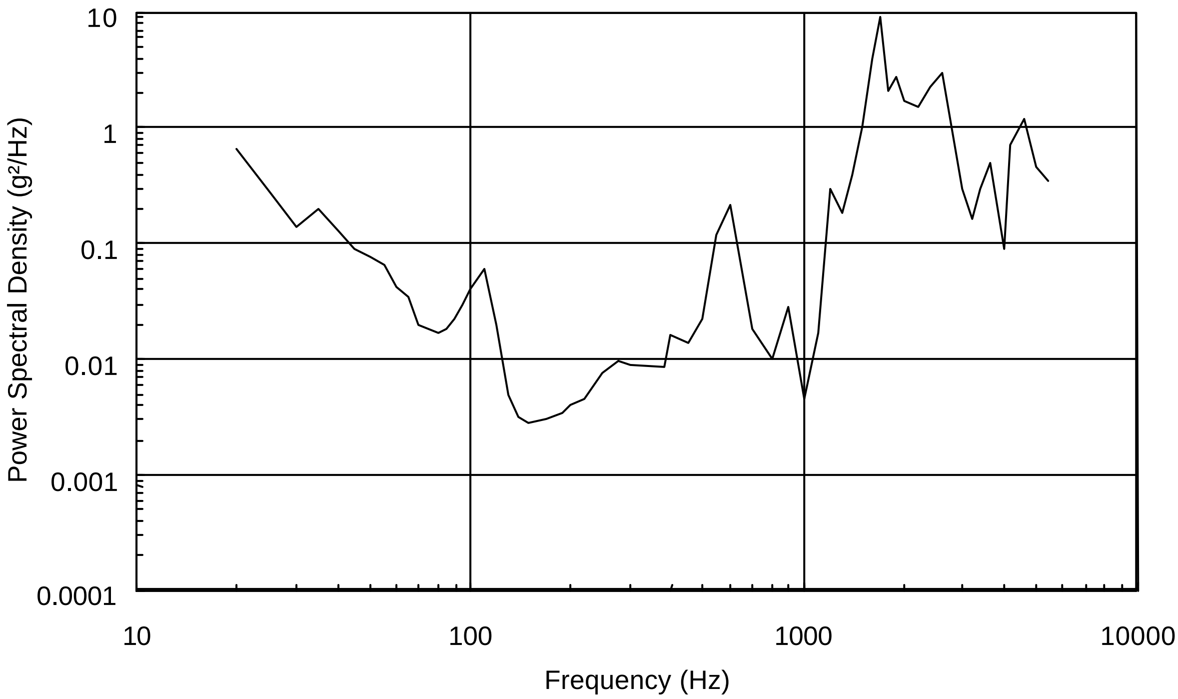


Figure 3 - Spectral responses of missile equipment adjacent to a ramjet motor

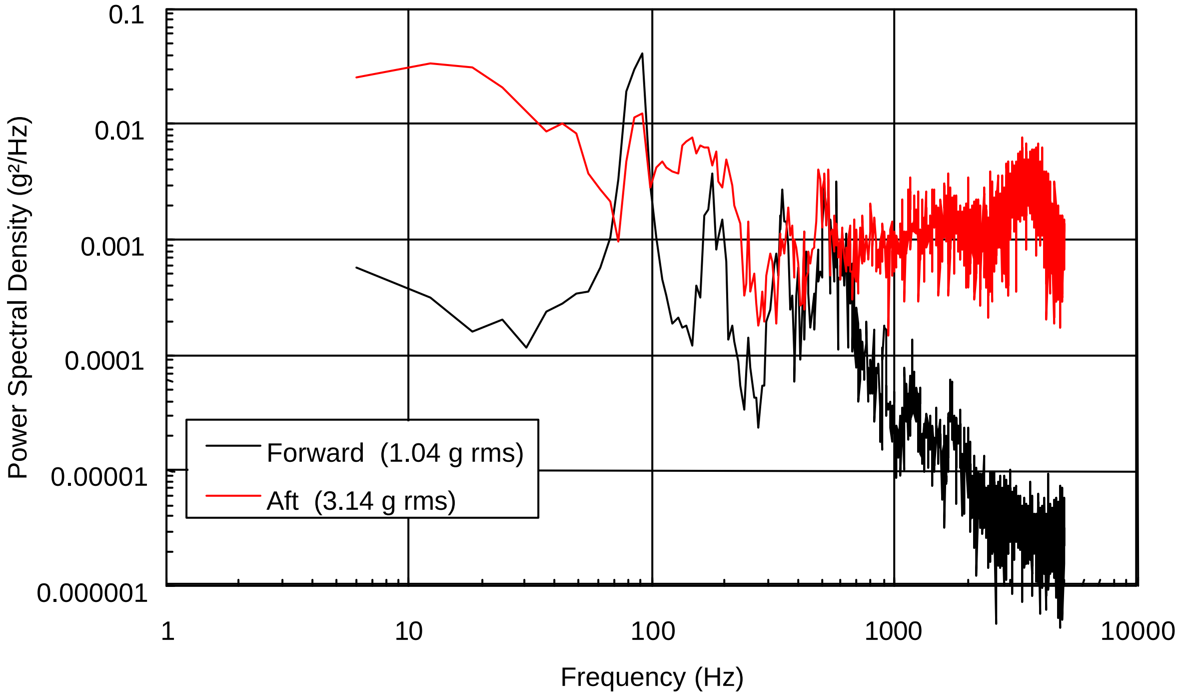


Figure 4 - Comparison of spectral responses of missile equipment at forward and aft locations within a solid propellant powered missile

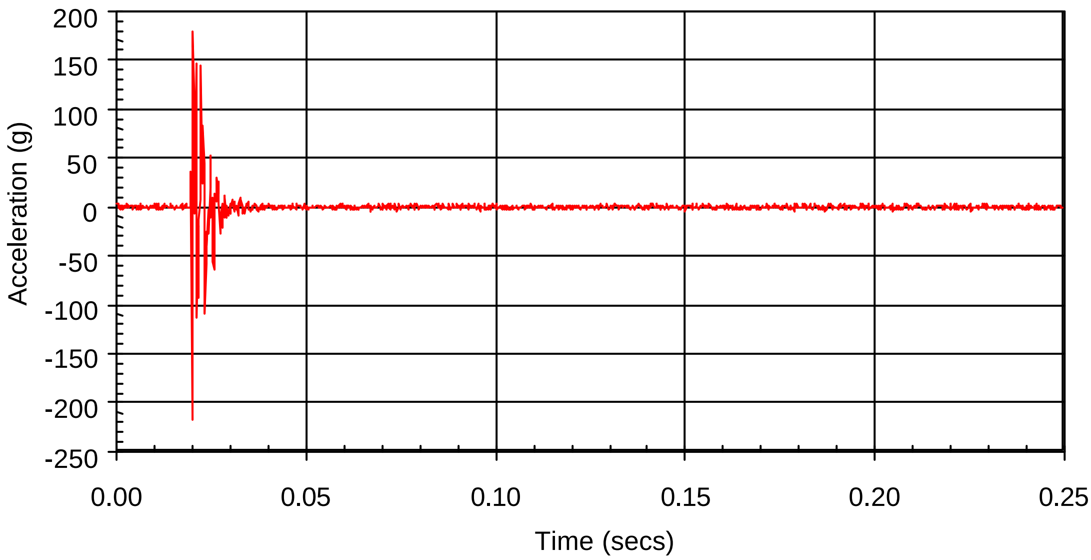


Figure 5 - Shock response history from close to the source

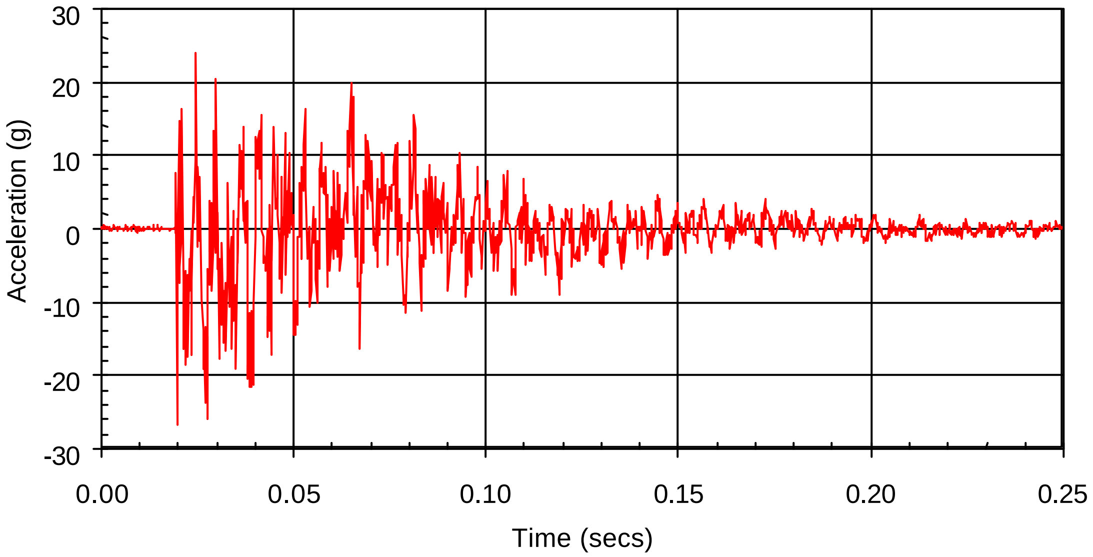
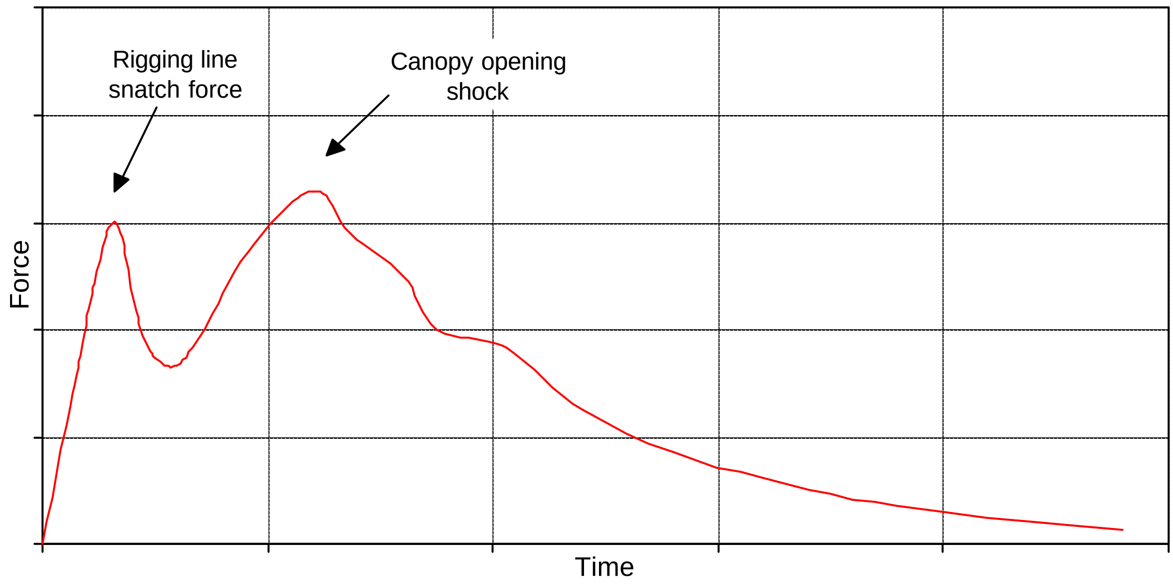
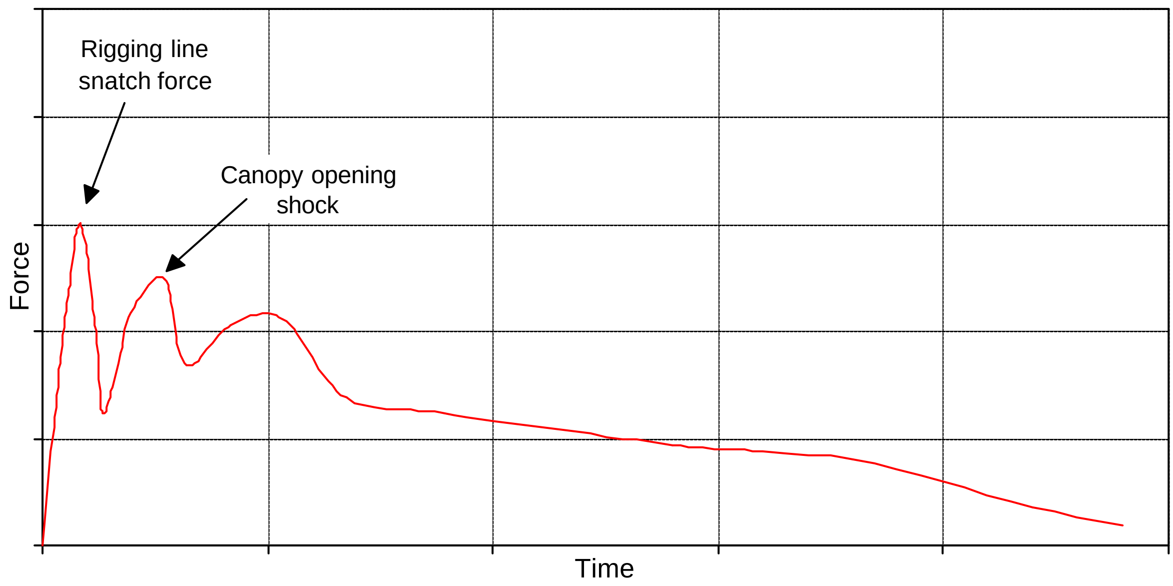


Figure 6 - Shock response history distant from the source



a. Large canopy and short lines



b. Small canopy and long lines

Figure 7 - Parachute inflation force histories

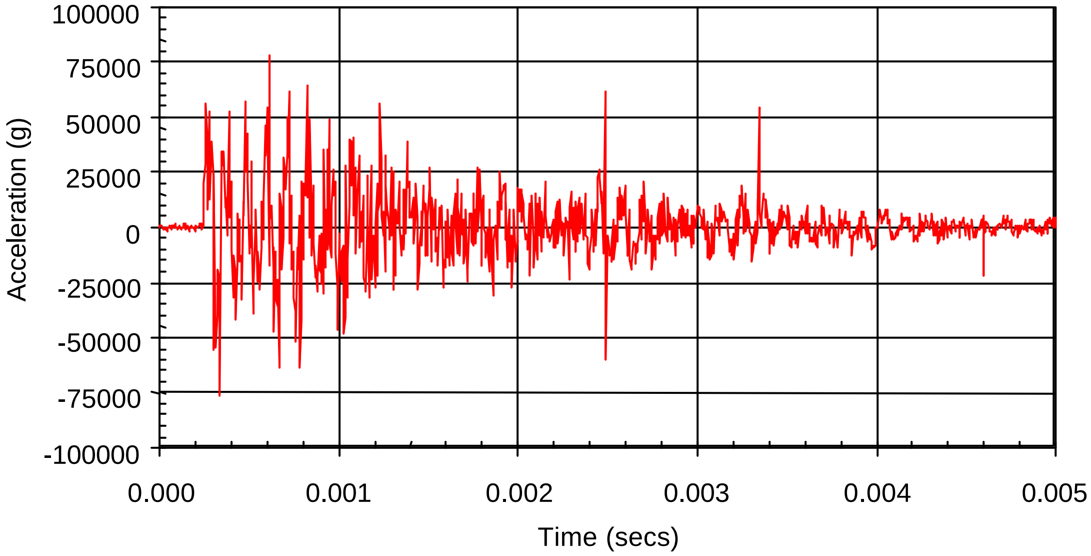


Figure 8 - Munition impact and penetration of concrete

SUB-SECTION 9/2 - UNDERWATER WEAPONS

1. GENERAL

1.1 This leaflet addresses the mechanical environments that may be encountered by underwater weapons, such as torpedoes and mines whose targets are predominantly below the surface of the sea, during their separation from the host platform and their autonomous progression to the target. The sources and characteristics of each environment are presented and discussed, and where appropriate information is given on potential damaging effects.

2. AIR LAUNCH - EJECTION TRANSIENTS

2.1 Severe transient accelerations are induced in stores such as torpedoes during their release by cartridge powered ejection release units (ERUs). The purpose of ERUs is to ensure the safe release of stores from high performance aircraft. Other devices, such as the various gravity release units used for releasing stores from helicopters, do not themselves induce significant transient loadings into stores.

2.2 Depending upon the particular aircraft/store combination, transients applied to stores by ERUs can attain acceleration levels up to 40 g, whilst pulse shapes are broadly half sine and durations typically within the range 10 to 40 ms. Ram ejection forces can attain 50 kN. Further details are referenced in AECTP-200 Leaflet 249/1.

2.3 The relatively high amplitudes and long durations of these pulses often produce critical design load cases. Consequently modelling and/or test firings are used to derive project specific, ie: tailored, load-time plots to which materiel is qualified. General purpose fall back or minimum integrity levels are not appropriate for ejection transients.

3. AIR LAUNCH - RELEASE DISTURBANCE

3.1 During release of a store from an aircraft any asymmetric ERU ejection forces will cause significant pitching motions, which will result in substantial aerodynamic pressure and acceleration forces being imparted to the store.

3.2 Aerodynamic design requirements for stores should ensure that these release disturbance forces are quickly damped out. Nevertheless, the applied forces experienced by the store can attain relatively high amplitudes and long durations, which may result in critical design load cases. Therefore modelling and/or wind tunnel testing is used to establish project specific, ie: tailored, loads to which a store is qualified. Fall back or minimum integrity levels are not appropriate for this condition.

4. TUBE LAUNCH

4.1 Munitions such as torpedoes launched from a submarine are likely to be subjected to the shock arising from compressed gas effects within the launch tube. Typically, acceleration severities along the longitudinal axis can attain peak values of around 25 g with durations around 20 ms. Peak values in the transverse axes can reach 32 g with durations around 15 ms.

5. DECK LAUNCH

5.1 Munitions launched from the deck of a surface ship may be subjected to shock loadings in the longitudinal axis of up to 60 g. The durations of these loadings are typically of the order of 8 ms.

6. OTHER LAUNCH MODES

6.1 Other launch modes such as Land Vehicle, Ground/Silo, Gun Barrel are addressed in Sub-section 9/1.

7. POWERED UNDERWATER MOTION

7.1 During powered underwater motion munitions such as torpedoes will experience vibration induced by water traversing the external surfaces, and also self induced vibration arising from out of balance motors and drive gear. However, tactical considerations dictate that acoustic propagation from such munitions requires to be extremely small, and therefore significant design effort is expended to minimise all vibration sources. The vibration characteristics are expected to be predominantly sinusoidal, whilst acceleration amplitudes are likely to be within 1 g and over the frequency range 20 to 500 Hz.

8. UNDERWATER MANOEUVRES

8.1 Whilst manoeuvring after launch, a munition such as a torpedo can be subjected to sustained acceleration loads. The severity of such loads is determined by tactical considerations, but in general they are unlikely to exceed 15 g.

9. UNPOWERED MOTION

9.1 For tactical reasons munitions such as mines or torpedoes may spend extended periods during which they are unpowered and undergo only subsidiary motion arising from previous powered or deployment phases. Any sources of vibration will be shut down to minimise acoustic propagation and detection. Therefore, the mechanical environment can usually be assumed to be limited to that of hydrostatic pressure, which is generally covered by static analysis.

10. SEPARATION AND STAGING

10.1 During munition separation and staging events the initiation of pyrotechnic devices, such as explosive bolts and line cutting charges, can result in severe shock loadings, which can take the form of stress waves and/or oscillatory acceleration transients. Further information is referenced in AECTP-200 Leaflet 249/1.

11. SPIN

11.1 To increase stability some projectiles or submunitions are subjected to spin during release. Spin rates vary considerably depending upon performance requirements. Therefore, it is inappropriate to recommend general purpose spin rates. Special purpose test facilities, such as using a motorised device to induce spin, may be required to induce high rates.

12. PARACHUTE RETARDATION

12.1 Parachute retarded munitions such as mines or torpedoes may be subjected to two significant acceleration transients during parachute deployment. The first transient is a snatch condition that occurs when the uninflated canopy is arrested by the rigging lines at the instant of full deployment. The second transient arises from the rapid increase in deceleration force during the inflation of the canopy. Further information is referenced in AECTP-200 Leaflet 249/1.

12.2 As underwater munitions are not normally deployed from high performance aircraft, loadings arising from parachute inflation are unlikely to exceed those arising from submarine launch tubes, i.e.: less than 25 g.

13. WATER ENTRY

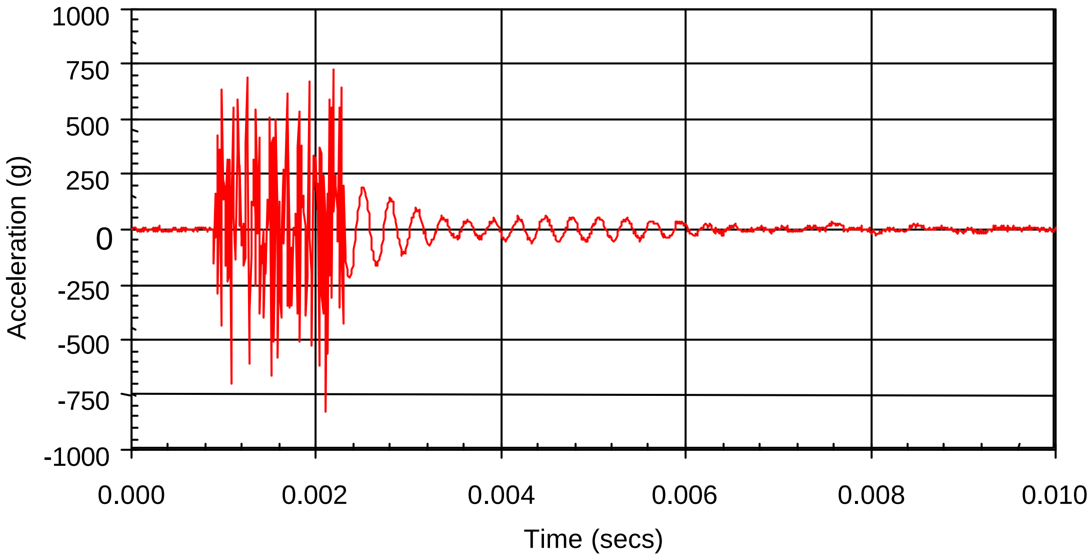
13.1 It is to be expected that response accelerations of torpedoes during water entry are dependant on parameters such as impact velocity, impact angle and nose geometry. As an indicator, at a store nose, peak acceleration levels of around 3000 g have been measured for water impact velocities of 80 m/s. A typical water entry time history and shock spectrum is shown in Figure 1, both of which demonstrate the high frequency acceleration components usually observed from measurements for this condition.

14. SUBMUNITION EJECTION AND IMPACT

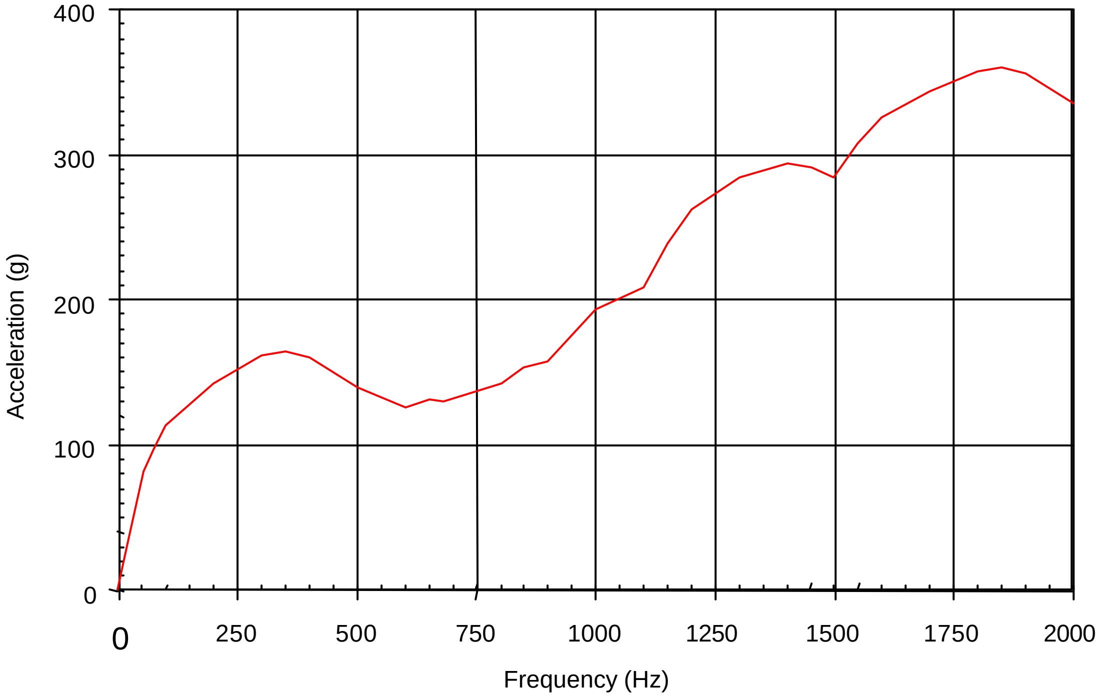
14.1 These conditions are addressed in Sub-section 9/1.

15. NOVEL APPROACHES

15.1 It is not possible in this document to address all the environmental conditions and particularly those that arise from novel approaches to design solutions. Moreover, it is usually necessary to conduct particular data acquisition programmes and to devise special test facilities for the conditions arising from novel approaches.



a. Shock history



b. Shock response spectrum (Q = 10)

Figure 1 - Example of water entry shock

Note: The shock response spectrum in (b) has not been derived from the shock history in (a).